



SHOUT
SHARE IT

STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION
NATURAL HISTORY SURVEY DIVISION
STEPHEN A. FORBES, *Chief*

BULLETIN

OF THE

Illinois State Natural History Survey

URBANA, ILLINOIS, U. S. A.

VOLUME XIV
1921—1923



PRINTED BY AUTHORITY OF THE STATE OF ILLINOIS

1925

STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION
A. M. SHELTON, *Director*

BOARD OF
NATURAL RESOURCES AND CONSERVATION

A. M. SHELTON, *Chairman*

WILLIAM TRELEASE, *Biology*
JOHN M. COULTER, *Forestry*
EDSON S. BASTIN, *Geology*
WILLIAM A. NOYES, *Chemistry*

JOHN W. ALVORD, *Engineering*
KENDRIC C. BABCOCK, *Representing the*
President of the University of Illi-
nois

THE NATURAL HISTORY SURVEY DIVISION

STEPHEN A. FORBES, *Chief*



SCHNEPP & BARNES, PRINTERS
SPRINGFIELD, ILL.
1925
30259—600

CONTENTS

ARTICLE I. THE ORCHARD BIRDS OF AN ILLINOIS SUMMER. BY STEPHEN A. FORBES AND ALFRED O. GROSS. (1 MAP, 6 PLATES) JUNE, 1921.....	PAGE 1-8
In Southern Illinois:	
Abundance of birds in general.....	2
The more abundant species.....	3
Farm and commercial orchards compared.....	5
Orchard birds <i>par excellence</i>	6
Economic relations	7
In central and northern Illinois.....	7
A bird's view of the orchard.....	8
ARTICLE II. ON THE DISTRIBUTION OF THE FRESH-WATER SPONGES OF NORTH AMERICA. BY FRANK SMITH. JUNE, 1921	9-22
Historical	9
Systematic	10
Illinois species	12
Additional North American records.....	14
Tabular presentation of distribution data.....	16
Literature dealing with fresh-water sponges of North America.....	18
ARTICLE III. A STUDY OF THE MALARIAL MOSQUITOES OF SOUTHERN ILLINOIS. II. OPERATIONS OF 1920. BY STEW- ART C. CHANDLER. (1 MAP, 2 TEXT-FIGURES, 2 GRAPHS) NOVEMBER, 1921	23-32
Introduction	23
Description of the breeding places at Herrin.....	23
The production of mosquitoes.....	26
Comparison of breeding places.....	27
Malaria in Herrin.....	29
Relation between malaria and the malarial mosquitoes.....	29
Species of mosquitoes at Herrin, 1920.....	30
Conclusion	32
ARTICLE IV. CHANGES IN THE BOTTOM AND SHORE FAUNA OF THE MIDDLE ILLINOIS RIVER AND ITS CONNECTING LAKES SINCE 1913-1915 AS A RESULT OF THE INCREASE, SOUTH- WARD, OF POLLUTION. BY ROBERT E. RICHARDSON. DECEM- BER, 1921	33-75
The Illinois River and Peoria Lake, Chillicothe to Wesley.....	35
The Illinois River, Liverpool to Havana.....	48

The Illinois River from 2 miles below Havana to 1.5 miles below the head of Grand Island.....	PAGE 54
Three all-bottomland lakes and one sand-beach lake between Liverpool and Havana	59
Stewart Lake, an all-bottomland lake of the shallower type, twenty miles south of Havana.....	70
Estimated reduction of midsummer surplus stocks in the combined acreage between Chillicothe and Lagrange.....	73
ARTICLE V. THE HELMINTHOSPORIUM FOOT-ROT OF WHEAT, WITH OBSERVATIONS ON THE MORPHOLOGY OF HELMINTHOSPORIUM AND ON THE OCCURRENCE OF SALTATION IN THE GENUS. BY F. L. STEVENS. (23 TEXT-FIGURES, 25 GRAPHS, 28 PLATES) JUNE, 1922.....	
	77-186
Introductory	77
Acknowledgments	77
I. A foot-rot of wheat and its causal fungus:	
Symptoms	78
Fungi present	78
Growth of the causal fungus on various media.....	79
Various agars as media.....	80
Summary concerning growth on agars.....	85
Rice and similar substances as media, with special note of color phenomena	86
Summary concerning growth on rice and similar substances.....	88
Miscellaneous vegetable media.....	88
Summary concerning the foregoing vegetable media.....	90
Cereal shoots grown from aseptic seeds as media.....	90
Environmental factors which induce variation.....	91
Quantity of nutriment.....	91
Inhibitory influences	93
Humidity of media.....	93
Humidity of air.....	94
Temperature relations	98
Light	99
Carbohydrates	100
Nutrients as affecting conidial length, septation, and shape.....	101
Summary concerning environmental factors which induce variation	102
Morphology of the foot-rot fungus.....	103
Mycelium	105
Senescence phenomena of aerial mycelium.....	107
Conidiophores	109
Conidia	110
Etiology of foot-rot:	
Evidences of etiological relation of H. No. 1.....	124
Constant presence of the pathogene.....	124
Absence of other constant parasites.....	124

	PAGE
Identity of pathogene proved by culture.....	124
Evidence of infectiousness.....	124
Conidia produced in moist-chamber culture.....	125
Evidence from inoculation.....	125
Recovery of organism.....	128
Infection phenomena on wheat.....	128
Susceptibility of various hosts to infection.....	137
Summary concerning etiology of foot-rot.....	139
II. Evidence and discussion of the occurrence of saltation within the genus <i>Helminthosporium</i> :	
Introductory	139
Characters of saltants as shown in transfers.....	141
Tendencies in saltation.....	145
Stability of the saltants.....	145
Stability of the saltants through the conidia.....	146
Apparent reversions	147
Supposititious causes of the variant sectors.....	147
Saltations from single conidia.....	149
Frequency of saltation.....	150
Saltation occurred on various media.....	152
Saltations and modifications occurring in test-tube cultures.....	152
Saltations in nature.....	154
Notes concerning selected individual saltants.....	155
General discussion of saltation.....	157
Taxonomy	164
Conclusion	168
Summary	168
Literature cited	171
Appendix:	
Methods	179
List of <i>Helminthosporium</i> s used for purposes of comparison.....	181
Discussion of foregoing list with several brief descriptions.....	184
ARTICLE VI. THE NUMBERS AND LOCAL DISTRIBUTION IN SUMMER OF ILLINOIS LAND BIRDS OF THE OPEN COUNTRY. BY STEPHEN A. FORBES AND ALFRED O. GROSS. (36 PLATES) APRIL, 1922	187-218
Numbers of gregarious and solitary species, respectively.....	190
Most abundant species, both years.....	192
The most abundant birds by sections of the state.....	194
The most abundant species of the whole state.....	196
Change of numbers from north to south.....	197
Birds and vegetation areas.....	199
The bird life of Illinois pastures.....	200
The meadow birds.....	201
Birds in small grain and in stubble.....	203
The birds of the corn field.....	205

	PAGE
Birds on plowed ground.....	206
The birds of the swamps.....	207
Birds of the open woods.....	207
Birds in orchards.....	209
Birds in shrubbery.....	210
Birds of the farmyard and garden.....	210
Waste and fallow lands.....	212
Summary and discussion.....	213
ARTICLE VII. CODLING-MOTH INVESTIGATIONS OF THE STATE	
ENTOMOLOGIST'S OFFICE, 1915, 1916, 1917. BY PRESSLEY A.	
GLENN. (8 TEXT-FIGURES, 7 GRAPHS, 3 CHARTS) AUGUST, 1922.....219-289	
Introductory statement	219
Definition of terms.....	219
General conclusions	221
Equipment and methods of work.....	223
Large-cage series	227
Life-history series	228
Band-record series	231
Influence of climatic conditions on the egg, larva, and pupa of the codling-moth	231
Zones of temperature.....	232
General procedure in the study of temperature relations.....	233
Relation of temperature to development of the egg.....	234
Relation of temperature to development of the larva.....	239
Relation of temperature to development of the pupa.....	246
Conclusions from the foregoing discussion.....	252
Observations on the life history of the codling-moth in 1915, 1916, and 1917	253
Incubation period	254
Larval period	254
Pupal period	256
Combined egg, larval, and pupal periods.....	256
Adult period	257
Total life period.....	257
Oviposition	258
Relation of temperature to length of development period.....	258
Seasonal history of the codling-moth, 1915.....	259
Large-cage series	259
Band collections	262
Summary of the seasonal history, 1915.....	263
Records for other points than Olney.....	264
General remarks on the season.....	264
Seasonal history of the codling-moth, 1916.....	265
Large-cage series	265
Band collections	267
Summary of the seasonal history, 1916.....	269

	PAGE
Records for several localities.....	271
Seasonal history of the codling-moth, 1917.....	272
Large-cage series	272
Band collections	273
Summary of the seasonal history, 1917.....	275
Relation of temperature to the seasonal history of the codling-moth...	275
Method of forecasting dates when the different stages of the several generations may be expected to appear at any given place in a normal season	281
How to compute effective day-degrees.....	282
Relation of temperature to time when larvae hibernate.....	283
Relation of humidity and evaporation to the rate of development of the codling-moth	284
Spray program for the codling-moth.....	288
 ARTICLE VIII. FIRST REPORT ON A FORESTRY SURVEY OF ILLINOIS. BY ROBERT B. MILLER. (30 PLATES, 1 PROFILES SHEET, 6 GRAPHS, 1 MAP) MARCH, 1923.....	291-377
Introduction	291
Acknowledgments	295
I. Land classification	296
The forest:	
History	297
Forest types	298
Detailed exhibit of stand of types, by counties, for area surveyed, and per cent. of it wooded.....	300
Important trees and their main uses:	
Hardwoods	302
Tabulated data obtained by a study of types of upland and bottom-land timber	313-317
Annual cut in board feet.....	317
Physiographic features:	
Topography	318
Drainage	319
Geology	320
Soil types	324
Climate	327
II. Milling and logging operations and wood-using industries in southern Illinois	327
List of mills, with location and output.....	330
The veneer industry.....	331
Manufacturers in the region, and products.....	332
Necessity for a local supply of "softwoods" for veneer purposes..	333
Charcoal-making: Processes and yields.....	334
Ties and mine timbers:	
Railroad cross-ties	335
Specifications, grades and sizes, species.....	335

	PAGE
Wood preservation and tie-treating plants in Illinois.....	337
Timber used in coal mines.....	340
III. Forest problems:	
Fires	342
Direct effects of fires.....	342
Injury to reproduction.....	343
Injury to the soil.....	343
Injury to productive power of the forest.....	344
Effect of severe burning upon young stands.....	346
Erosion	346
Grazing	347
IV. Forest policy and management.....	348
The upland timber belt.....	348
Outline of proposed fire-protection system for upland timber belt..	348
The so-called farm wood-lots.....	349
The overflow bottomlands.....	350
V. Volume and growth studies.....	350
Stem analysis	351
Bibliography	354
Appendix:	
Volume tables for leading species, and taper and growth tables and graphs for white and black oak.....	357
ARTICLE IX. THE DETERMINATION OF HYDROGEN ION CON- CENTRATION IN CONNECTION WITH FRESH-WATER BIOLOG- ICAL STUDIES. BY VICTOR E. SHELFORD. (1 TEXT-FIGURE, 1 GRAPH) FEBRUARY, 1923.....	379-395
Introduction	379
Methods of determining H ion concentration (pH).....	380
The influence of hydrogen ion concentration on fertilization, develop- ment, growth, and survival in water deficient in oxygen.....	381
Reactions of fish to differences in hydrogen ion concentrations.....	385
An examination of certain Illinois waters with special reference to hydrogen ion concentration.....	386
General relations of hydrogen ion concentration to other factors.....	388
Discussion and summary of results.....	391
Conclusions	392
Acknowledgments	394
Bibliography	394
ARTICLE X. ON THE NUMBERS AND LOCAL DISTRIBUTION OF ILLINOIS LAND BIRDS OF THE OPEN COUNTRY IN WINTER, SPRING, AND FALL. BY STEPHEN A. FORBES AND ALFRED O. GROSS. OCTOBER, 1923.....	397-453
The winter birds.....	397
The data by sections of the state.....	400
Residence classes and their seasonal movements.....	402

	PAGE
Winter birds in habitats.....	404
The spring migration period.....	415
Spring birds in habitats.....	424
The fall migration period.....	424
Fall birds in habitats.....	429
General summary of the most abundant birds.....	431
Concerning the methods of the survey.....	435
General species list.....	436
Examples of field notes, index cards, and principal tables made up from them	448

ERRATA

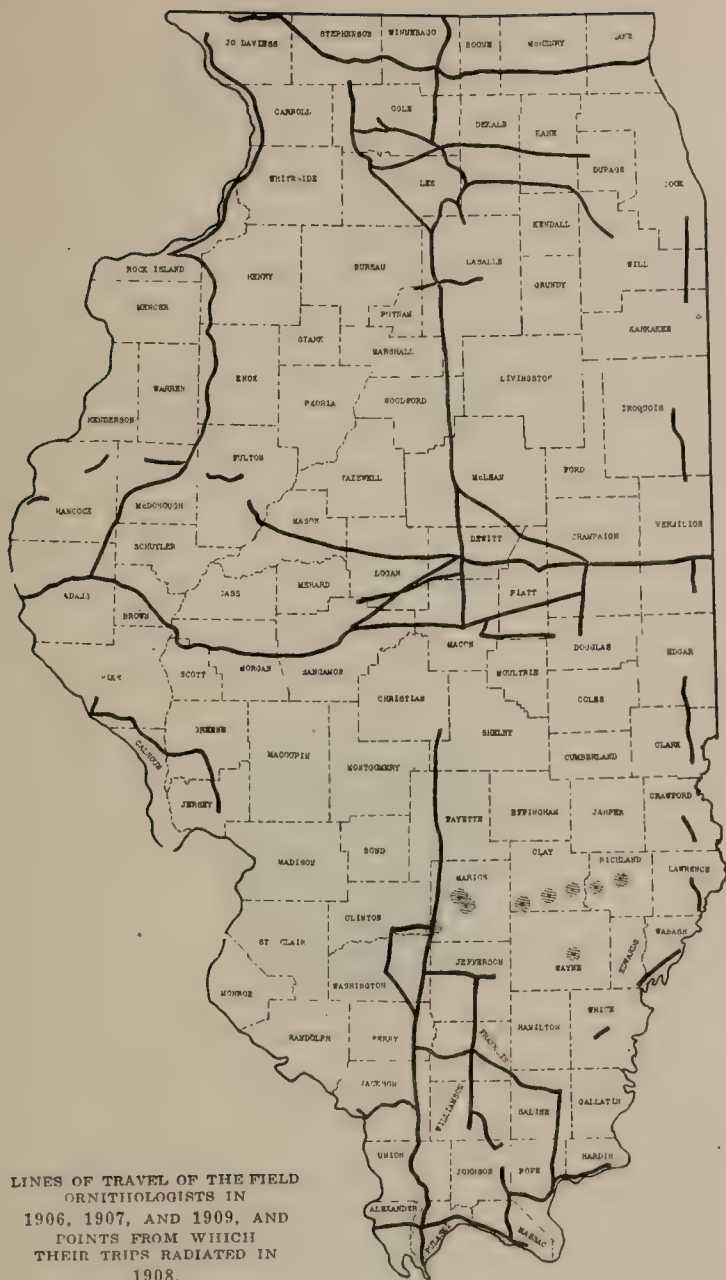
Page 44, line 1 of text, for "sludge-worms" read *midge larvae*, and for "larvae of the midges" read *sludge-worms*.

Page 188, line 4, for 3 read 23.

Page 216, last line, for "the opposite page" read *page 214*.

Page 267, delete line 13 from bottom.

Page 382, lines 3 and 5 from bottom, for "decrease" read *change*.



STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION
DIVISION OF THE
NATURAL HISTORY SURVEY
STEPHEN A. FORBES, Chief

Vol. XIV.

BULLETIN

Article I.

THE ORCHARD BIRDS OF AN ILLINOIS SUMMER

BY

STEPHEN A. FORBES
and
ALFRED O. GROSS,



PRINTED BY AUTHORITY OF THE STATE OF ILLINOIS

URBANA, ILLINOIS

June, 1921

STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION
W. H. H. MILLER, *Director*

BOARD OF
NATURAL RESOURCES AND CONSERVATION
W. H. H. MILLER, *Chairman*

WILLIAM TRELEASE, *Biology*
JOHN M. COULTER, *Forestry*
ROLLIN D. SALISBURY, *Geology*
WILLIAM A. NOYES, *Chemistry*

JOHN W. ALVORD, *Engineering*
KENDRIC C. BABCOCK, *Representing the*
President of the University of Illi-
nois

THE NATURAL HISTORY SURVEY DIVISION
STEPHEN A. FORBES, *Chief*



SCHNEPP & BARNES, PRINTERS
SPRINGFIELD, ILL.

1921

47054—1200

ARTICLE I.—*The Orchard Birds of an Illinois Summer.* By
STEPHEN A. FORBES AND ALFRED O. GROSS.

From 1894 to 1917 the Illinois State Laboratory of Natural History (since merged in the Natural History Survey of the State), of which the senior author of this paper was director, was active in quantitative studies of the plankton of the rivers and lakes of Illinois, making common use, in securing collections, of a ring net of very fine mesh, hauling it definite distances and at a fixed rate, measuring the product of each haul, identifying and sometimes counting the plankton organisms collected, bringing into comparison by this means the yield of different waters, situations, and seasons, and drawing such inferences as to cause and condition as were warranted by the data so obtained.

Having realized for many years the urgent need of numerical data concerning the species of birds in the state as indispensable to their valuation as ecological, and especially as economic, agencies it occurred to the senior author in 1905 that an equivalent of the plankton method might be used in the ornithological field by putting in place of the plankton net two men who should walk in parallel lines a definite distance apart, should identify and count all the birds flushed by them or crossing their track on a strip of a given width—say 150 feet—and should make at the same time a precise record of the kinds of surface and situations which they were traversing, of the distances traveled over each successively, and of the kinds of birds seen and the numbers of each kind on each such section of the 150-foot strip. The product of such a series of expert observations would be like that of a huge net a hundred and fifty feet wide, drawn in straight lines across every kind of crop or other surface vegetation,* by which all the birds found there should be caught and held until they had been identified and counted. The data so obtained would evidently be quite as useful for their purpose as those of the plankton net, and the results of their collation and analysis would be quite as dependable.

A satisfactory test of the method having been made during the summer of 1905 on a 400-acre grain and stock farm belonging to the University of Illinois, two assistants were engaged, both students of the University at the time—one the junior author of this paper, who was responsible for the identification and counting of the birds, and the other a companion whose duty it was to walk at a measured pace at a fixed distance to the left of his leader, and to count and record the number of

* Forests of tall trees were avoided, since the birds there could not be listed exhaustively; and in orchards, the more open woods, patches of close shrubbery, and the like, the strip surveyed was usually narrowed to sixty feet.

steps taken over each kind of situation. It was the original plan to devote a single year to these observations, dividing each of the successive seasons between the three sections of the state—northern, central, and southern—in such a way that we might have a detailed and carefully shaded picture of the bird life of each section in all four seasons of the year. This plan was carried through successfully for a year beginning August 29, 1906; and additional trips were made for special purposes during the late summer of 1908 and the entire summer season of 1909. The distribution throughout the state of the trips of the bird observers during these years is shown in the accompanying map. These trips, all taken on foot, aggregated 2,825 miles, and on them 64,685 birds were recognized and counted.

Two brief papers have been published by the senior author on parts of the product of these trips, as preliminary examples of their use; one on "An Ornithological Cross-section of Illinois in Autumn,"* and the other on "The Midsummer Bird Life of Illinois,"† the first based on a trip across the center of the state from the Indiana line to the Mississippi River, and the second treating of the summer data of the year 1907.

The widely separated residences of the present authors, one of us living in Maine and the other in Illinois, and the many engrossing preoccupations of both, have made it impossible until now for us to have the personal conferences or to provide for the cooperation necessary to a complete treatment of our subject; and it is with pleasure that we at last find ourselves in a position to work together through the mass of tables long ago made ready, and to avail ourselves, in their discussion, of the copious field notes and valuable reminiscences of Professor Gross, often quite essential to an interpretation of our data. We now hope to prepare, without undue delay, a series of papers, the first of which is here presented.

IN SOUTHERN ILLINOIS

Abundance of Birds in General.—In the summers of 1907 and 1909, statistical data of the bird life of southern Illinois were obtained by the methods above described, in the form of a record of the species of birds and the numbers of each found on 5,527 acres of land chosen entirely at random, and this showed that orchards were decidedly the favorite places of bird resort at that season and in that part of the state. While the general average number for the whole area studied was 768 birds to the square mile, the number to that area in the orchards traversed was 2,969—or nearly four times the general ratio. Woodlands came next in density of the bird population, with 1,794 birds per square mile; yards and gardens third, with 1,339; and shrubbery fourth, with 1,054 to the mile. The high rank of yards and gardens as a bird resort was due mainly to the semi-domesticated English sparrow; and with this eliminated, orchards, open woodlands, and shrubbery—

* *Bul. Ill. State Lab. Nat. Hist.*, Vol. VII, pp. 305-335.

† *Ibid.*, Vol. IX, pp. 373-385.

the "forest edge," in short—were found to be by all odds the favorite places of resort of the native southern Illinois species. The only other situation in which the numbers were above the average was pasture land, with 937 to the square mile. The ratios in corn and oats were 423 and 419 to the mile, respectively. Other situations studied, and ratios in each, were stubble fields, 606; wheat and rye, 580; plowed ground, 626; waste and fallow, 708; and swamps, 710.

The more Abundant Species.—The most abundant bird in the area traversed was the English sparrow, about 14.5 per cent. of all the birds seen belonging to this species. Its average density in the whole area was 92 to the square mile, while in orchards it was 427—that is, this species was between four and five times as abundant in orchards as its average for the general range. It was of course more abundant in yards and gardens, averaging there 597 to the square mile. In pastures and fields of small grain its numbers were 103 and 178 to the mile, respectively. These data are in evident agreement with what we know of the habits of the sparrows. As they both feed and nest most commonly in yards and gardens—that is, in the neighborhood of the house premises—they naturally resort to orchards most frequently for perching places—that is, for rest, shelter, and refuge. They are attracted to pastures by the fragments of grain to be found in the droppings of stock, and they turn to grain fields for food at harvest time. In meadows, on the other hand, they find little of either food or shelter, and hence average there only 53 to the square mile, or one sparrow to each twelve acres. English sparrows are not injurious in orchards, and their abundance there may be of some small benefit in their capture of insects, especially as food for their young.

Next on our list in order of abundance in orchards is the mourning dove. With a general average density of 60 to the square mile for the whole area, its ratio in orchards was five times as great, or 297 to the mile. Its other ratios larger than its general average were stubble fields, 111; small grain, 102; plowed ground, 74; yards and gardens, 67. The number of this species in the orchard seems to have no economic significance, as the mourning dove feeds mainly on seeds of wild plants, and to some extent on grain. It nests largely in trees, and this is probably why the orchard is its favorite resting place.

The common quail, or "bob white," came next in order of numbers, according to our data derived from 241 quails seen on these trips, so distributed as to give us ratios of 289 to the square mile in orchards, 48 in shrubbery, 43 in stubble, 35 in woodlands, and 29 in grain fields, the other numbers being smaller than the general average for the whole area, which was 28 to the square mile. The number seen seems small for general conclusions; but the preference of the quail for orchards in southern Illinois is still more clearly shown by our more abundant data from commercial orchards, given on page 7. Evidently it is not the trees that attract it, but the cover afforded by an undisturbed growth of grass and weeds between the rows. Several nests

of quail were found here, and this was the only situation in which the parent birds were seen with downy young.

If we may judge of the fitness of the common name of a bird from the outcome of our statistical tabulations, we should say that the next one on our list, commonly known as the field sparrow, ought to be named the orchard sparrow or the bush sparrow instead, (the last, indeed, a name given it by John Burroughs,) for it was more abundant in orchards and in shrubbery than anywhere else, numbering 251 and 257 respectively to the square mile in these situations. Those in which it was next most abundant were open woods, with 88 to the square mile, and pastures and fields of waste and fallow land, with 57 to the mile in each. The average for the whole area covered was 37 to the square mile.

There can be no doubt of the correctness of the name of the orchard oriole, our data for which gave us an average of 168 to the square mile in orchards, with a general average for the whole area covered of only 12. Its only other habitat worth mentioning is yards and gardens, in which there were 44 orioles to the square mile.

Our good little friend the robin, of which 164 were seen, was also largely an orchard and woodland bird, its density ratio being 145 to the mile in orchards and 89 in woodlands, with only 19 as an average for the whole area. Other notable ratios were 27 to the mile in pastures and 46 on plowed ground. Its frequency in farm orchards is probably due, like that of the English sparrow, to its general abundance about the home premises, from which an orchard is often the nearest available resort for shelter, rest, and nesting places.

The next species in order of abundance in orchards was the crow blackbird, or bronzed grackle. As represented by the 274 of these birds seen, it was more abundant in orchards than in any other place. With a general average density of 32 to the mile, its numbers stood at 137 in orchards, 70 in open woods, 47 in farm yards, 46 in pastures, 32 in corn, and 31 in fields of wheat and rye, and it fell below its general average in all the other situations.

Next, the blue jay, although less frequently seen in orchards than any of the birds already mentioned, averaged there 114 to the square mile. It was still more abundant in open woods (195 to the mile), and much less so in pastures (24). Its general average for the whole area was only 13 to the square mile. It is thus essentially a woodland bird, resorting to orchards mainly because of their likeness to woods.

The mocking-birds seen on these southern Illinois trips numbered 115, and the brown thrashers, 137, equivalent to 13 to the square mile for the mocking-bird and 16 for the brown thrasher—numbers perhaps too small from which to draw definite conclusions as to their preferred surroundings. So far as our data go, however, they indicate a decided preference of both these birds for orchards, the orchard ratio to the square mile being 84 for each. The mocking-bird was still more abundant in farm yards (113) and above its general average in gardens (38) and

pastures (20); and the thrasher was quite as frequent in open woods (88) as in the orchard, and above its average in waste lands and in pastures (23 in each).

There were 42 species of birds seen and recognized in orchards on these summer trips in southern Illinois, and these taken together averaged 2,971 to the square mile in that situation. On the other hand, the just-mentioned ten species taken together averaged 2,096 to the square mile in orchards; and we have only 875 to the square mile of orchards for all the other 31 species. That is, 72 per cent. of all the birds found in orchards belonged to 26 per cent. of the species, and all the others taken together average only a little more than one to the acre of orchard—much too few to have any great importance in that situation.

Farm and Commercial Orchards Compared.—The foregoing discussion of orchard birds is based on the data of a general survey of the country made without particular reference to any special kinds of crops, orchards being brought into the account only as they chanced to lie in the lines of travel taken. The entire orchard area surveyed, in fact, aggregated only 84 acres, which was about 1.5 per cent. of the whole area from which all the birds were determined. In order to get material for a better knowledge of the bird life of the southern Illinois orchard, a visit was made in 1908 to a commercial-orchard district extending from Centralia to Olney, and there the time was spent from August 19 to September 15 of that year, exploring orchards primarily, and other situations only as these were crossed in going from one orchard to another. The area covered by this survey aggregated 1,369 acres—about a fourth as much as was covered in the two summers of 1907 and 1909; but the orchard tracts examined aggregated 774.5 acres instead of the 84 acres of the more general surveys, and taken together made more than 56 per cent. of the total area studied instead of the 1.5 per cent. in the other case.

The distances traveled on all these several journeys were 7.8 miles through farm orchards and 129 miles through commercial orchards, and in both cases all the birds on a strip sixty feet wide were determined and counted.

Several interesting differences were made out by a comparison of the products of these two kinds of surveys. In the first place, the number of birds per square mile of *all crops* was, as we should expect, considerably greater in the commercial-orchard district than in the farmland area—945 as compared with 769—a difference of nearly a fourth in favor of the commercial-orchard district. Nevertheless, the number of birds per square mile of *orchards* was much greater in the general farm surveys of 1907 and 1909 than in the orchard district survey of 1908—2,969 to the orchard mile in the former and only 915 in the latter. That is, a square mile of commercial orchards contained only about a third as many birds on an average as a square mile of farm

orchards. It is easy to see why this should be so. If, as we have already found to be the case, there are birds which resort to orchards for special purposes, we should expect to see them coming together in larger numbers to the unit of area in small, scattered orchards than in large orchards rather near each other. Indeed, we might well have expected that this concentration of birds in the orchards of a general farming district would have gone much farther than it has. In diminishing the ratio of orchards to other lands some thirty-seven times, we have increased the density of the bird population of the orchard only three times—evidence that the orchards are at best a convenience rather than a necessity to most of the birds which are found in them.

Comparing the lists of dominant species in the orchards of the two surveys, we find that while there were 42 species found in our 84 acres of farm orchards, 11 of which species made up 72 per cent. of the whole, there were 72 species found in the 774.5 acres of commercial orchards, 9 of which made up 87 per cent. of the whole number, and that 6 of the 9 dominant species were common to both lists. These were the quail, field sparrow, blue jay, mourning dove, brown thrasher, and English sparrow.

It was rather surprising to find the English sparrow first on the list of the most abundant farm-orchard birds and last on the corresponding commercial-orchard list, with 407 to the square mile in the first situation and only 56 in the second—seven or eight times as abundant in the farm orchard as in the commercial orchard; but this was no doubt due in great part to a fact already mentioned, that the center of abundance for this bird is in yards around the house and barn, and that it simply spreads from these to the adjacent orchards for shelter and refuge, with the result that its numbers per square mile of orchards is much smaller in a district where orchards are large and numerous than where they are small and few.

The fact that the number of mourning doves to the square mile was but 77 in commercial orchards, while it was 297 in the small orchards of the farm, may have a similar explanation, the orchard being one of the favorite nesting places of this bird. On the other hand, the quail, the field sparrow, and the blue jay were even more abundant to the mile in the commercial than in the farm orchard, and the brown thrasher was but little less so; but the orchard oriole and the robin, occurring in farm orchards at ratios of 168 and 164 to the square mile respectively, were not once met with in the 129 miles of travel through these commercial orchards. This fact was due in all probability, to the relatively late period of the observations of 1908, falling, as they did, beyond the nesting season of these birds.

Orchard Birds par excellence.—In view of the fact that in the commercial-orchard district only 56 per cent. of the area studied was actually in orchards, the remainder being made up of the usual variety of farm situations, it seems to us that if there were distinctive orchard species of birds, they should be distinguished here by their much larger

numbers per square mile in orchards than in miscellaneous situations; and an application of this test gives us the eight species of the following table, which may be taken, according to our data, as southern Illinois orchard-birds *par excellence*.

PRINCIPAL ORCHARD BIRDS PER SQUARE MILE, SOUTHERN ILLINOIS SURVEY,
SUMMER OF 1908.

Orchards compared with all other situations.

	Number of birds seen	Per square mile	
		In orchards (774.5 acres)	Not in orchards (595 acres)
Quail	431	356	32
Field sparrow.....	333	275	10
Blue jay.....	190	157	12
Mourning dove.....	93	77	26
Goldfinch	83	69	5
Cardinal	81	69	2
Carolina chickadee.....	71	59	3
Brown thrasher	70	58	3
Total per square mile		1,120	93

This small group of species seems strongly attracted to the orchard as the most desirable place of residence or resort, either for food, nesting, or shelter and refuge, of all the situations covered by our survey—a peculiarity which distinguishes it from the other species of our list whose occurrence in orchards is occasional and temporary, or at most secondary to their choice of some other situation.

Economic Relations.—Taken as a whole, these orchard birds of southern Illinois, occasional visitors as well as resident species, are not directly injurious there to the orchard or its products, except as a few of them may eat cherries; and nearly all of them are more or less beneficial because of their partially insectivorous habits, especially when foraging for their young. Of course no such group of bird residents can be expected to keep the injurious insects of their neighborhood down to the level of harmlessness, but they may exercise a constant restraining influence on insect multiplication and do their part towards checking incipient uprisings of species whose rate of increase is temporarily stimulated by unusually favorable conditions.*

IN CENTRAL AND NORTHERN ILLINOIS

During the summers of 1906, 1907, and 1909, trips were made in northern and central Illinois similar to those above described for the

* See a paper by the senior author on "The Regulative Action of Birds upon Insect Oscillations," Bul. Ill. State Lab. Nat. Hist., Vol. I, Art. 6.

southern part of the state, these northern and central trips covering 11,198 acres (6,210.4 acres in northern and 4,987.87 in central Illinois). Orchards were much less numerous, especially in northern Illinois, than in the southern part of the state, the area of farm orchards covered aggregating only 3.69 acres for the northern and 14.14 for the central part of the state, the former .07 of 1 per cent. and the latter .3 of 1 per cent. of the whole area on which the birds were determined and counted. These areas seem to us too small for detailed discussion, but a comparison of the observations made in them with those of the 84 acres of southern Illinois gives us some interesting results.

Consistently with what has already been said, the orchard birds were more than twice as numerous per square mile in central and northern Illinois orchards as in the more numerous and extensive farm orchards of the southern part of the state, averaging 6,246 to the mile in place of 2,969 in southern Illinois. This preponderance was mainly due, however, to the abundance of the English sparrow, which made more than 68 per cent. of the number of birds seen in orchards, instead of the 14.5 per cent. in southern Illinois. This is consistent with conclusions drawn from the midsummer observations of 1907, to the effect that the English sparrow diminished in numbers in that year from north to south.* Taking into account the native birds only, the ratios are 1,974 to the mile for the northern two-thirds of Illinois and 2,545 for the southern third; and this, again, agrees with the statement of the paper just cited, that the native summer birds increased in number from north to south in 1907. The larger number of the sparrow to the northward has also had the effect to reduce orchards to the second place on the list of situations preferred by birds, farm yards standing first.

A BIRD'S VIEW OF THE ORCHARD

An orchard is to us essentially a tract of land set to fruit trees in regular rows—in southern Illinois almost entirely to apple, peach, or pear; but we have already seen evidence that to some of the birds inhabiting it the trees may be of secondary importance and perhaps of very little interest; and we shall fail to understand an orchard as a bird resort unless we view it with the eyes of a bird instead of those of a man. It was, in fact, very obvious that a well-kept orchard, in which the ground was free from tall grass or bushes, was a rather poor place for birds (see Plates 1 and 2) but that one in which grass and weeds grew freely, and especially one in which dewberries and other shrubs were abundant, was a situation preferred above all others. It is this kind of ground-cover and the trees taken together—the latter useful to some for nesting and to nearly all for shelter against storms and for refuge from their enemies—which make up a complete bird orchard, answering to the essential needs of the orchard birds of this discussion (Plates 3—6).

* The Midsummer Bird Life of Illinois. Loc. cit., Vol. IX, pp. 373-385.

PLATE I



Clean orchard near Xenia, Clay Co.

PLATE II



Clean orchard near Flora, Clay Co., Aug. 28, 1908.

PLATE III.



Pear orchard, Flora, Clay Co., quail's nest found near tree in foreground.

PLATE IV.



Quail's nest, with 16 eggs, from orchard near Benton, Franklin Co., June 22, 1907.

PLATE V.



Orchard of grass, weeds, and dewberries, near Salem, Marion Co.

PLATE VI.



Edge of old neglected orchard near Arcola, Douglas Co., June, 1908.

STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION
DIVISION OF THE
NATURAL HISTORY SURVEY
STEPHEN A. FORBES, Chief

Vol. XIV.

BULLETIN

Article II.

DISTRIBUTION OF THE FRESH-WATER
SPONGES OF NORTH AMERICA

BY

FRANK SMITH



PRINTED BY AUTHORITY OF THE STATE OF ILLINOIS

URBANA, ILLINOIS

June, 1921

STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION
W. H. H. MILLER, *Director*

BOARD OF
NATURAL RESOURCES AND CONSERVATION

W. H. H. MILLER, *Chairman*

WILLIAM TRELEASE, *Biology*
JOHN M. COULTER, *Forestry*
ROLLIN D. SALISBURY, *Geology*
WILLIAM A. NOYES, *Chemistry*

JOHN W. ALVORD, *Engineering*
KENDRIC C. BABCOCK, *Representing the*
President of the University of Illi-
nois

THE NATURAL HISTORY SURVEY DIVISION
STEPHEN A. FORBES, *Chief*



SCHNEPP & BARNES, PRINTERS
SPRINGFIELD, ILL.

1921
47053—1200

ARTICLE II.—*On the Distribution of the Fresh-Water Sponges of North America.** BY FRANK SMITH.

In the preparation of this paper there have been two purposes in mind. One of these is the presentation of the results of studies thus far made on the fresh-water sponges of Illinois; and the other is to assemble in more convenient form the information which we now have concerning the distribution of such sponges in North America. Preliminary to the more detailed presentation of data it is desirable to give a brief summary of our knowledge of the fresh-water sponges of this continent.

HISTORICAL

The greater part of what is known on the subject at the present time is the result of the work of less than a half dozen men, and was gained during the decade 1880—1890. The most important work is that of Dr. Edward Potts, of Philadelphia, who contributed something over twenty short papers on the subject, besides his monograph—which appeared in 1887. Most of his papers appeared in the Proceedings of the Philadelphia Academy of Sciences. His collecting was done chiefly in Pennsylvania and New Jersey, in the vicinity of Philadelphia. An active co-worker with Potts was Henry Mills, of Buffalo, N. Y., who collected in his own state and occasionally in Florida, Iowa, and northern Illinois. About a dozen brief papers and a few new species appear to his credit. His publications were chiefly in various journals of microscopy which abounded in the decade just mentioned. A. H. McKay, principal of an academy in Halifax, N. S., was an active collector in Nova Scotia and Newfoundland, and contributed a half dozen papers and a few species of uncertain status. B. W. Thomas, of Chicago, a devotee to microscopy, did a good deal of collecting in northern Illinois for other workers, but not much writing. This quartet of workers was in close relation with H. J. Carter, of England, who was one of the leading specialists in the whole group of sponges, and they with certain Canadian collectors supplied Carter with material which served as a basis for a few papers on American forms and for one new species.

Of the approximately thirty known species of North American fresh-water sponges, about twenty were described during this decade, chiefly by Potts, and but one of them by a European. Some ten or eleven species were found in each of the states of Pennsylvania, New Jersey, and New

* Contributions from the Zoological Laboratory of the University of Illinois No. 174.

York, and a similar number in Nova Scotia and Newfoundland; also eight each in Florida and Illinois. In the following decade, (1890—1900) Ohio was given a list of ten species, chiefly through the work of D. S. Kellicott, who published two small papers on the subject of fresh-water sponges. In 1916 the writer published a list of nine species for Michigan, this being the number found in connection with his work at the University of Michigan Biological Station at Douglas Lake, in the northern part of the state. In 1918 he also published the description of a new species from Oneida Lake, in the state of New York. A study of Illinois material collected by various investigators has brought the list for the state up to twelve species, which is the maximum number for any state, as far as is known to the writer. Almost nothing is known of the sponge fauna of any state west of the Mississippi River and, with the exception of Florida, almost nothing of the sponge fauna of the southern half of the United States. Mills listed four species in Iowa, and the writer has found four species in the high-altitude lakes near Tolland, Colorado, in the vicinity of the University of Colorado Mountain Laboratory. As far as is known to him, not more than three species are recorded from any other state west of the Mississippi River. He will welcome information concerning more extended lists, if there be such. There is some evidence that the sponge fauna of the southern states will be found to differ in some respects from that of the northern ones. During the past fourteen years, N. Annandale, of the Indian Museum in Calcutta, has published numerous and important papers on fresh-water sponges, chiefly those of Asiatic regions; a few of them, however, have dealt with North American species. He has created one new genus, *Asteromeyenia*, for two of such species, and announced a few new locality records for others. His work was based on rather scanty collections belonging to the United States National Museum.

Four North American species were first found and described in Europe; while seven species first described in North America were subsequently found in Europe, and at least three of them also in Asia. About one third of our species are thus more or less widely distributed in the Northern Hemisphere.

SYSTEMATIC

Important characters for the recognition of species are found in the spicules of the skeleton; in other spicules which may or may not be present in the sponge mass and are variously designated as flesh spicules, dermal spicules, or sarcoderm spicules; and in still others, known as gemmule spicules, which are intimately related to the gemmules. The gemmules are small seed-like bodies appearing in summer or autumn, and are involved in one important method of reproduction. In a few species the apertures of the chitinous walls of the gemmules are at the summit of tubular prolongations, and these in turn are sometimes provided with one or more filaments, borne at or near the margins of the apertures. For the positive identification of nearly all of our species, the presence of gemmules is necessary.

The most serious defects in the work of Potts and his co-workers and of more recent workers who have depended on his monograph, have been due to the failure to recognize *Ephydatia fluviatilis* and *E. mülleri* as distinct species. These are two very abundant and widely distributed forms and are also highly variable. Specimens of either species were indiscriminately designated *Meyenia fluviatilis*, and nearly a dozen supposed species and varieties were named and described from various forms of one or the other of the two, and later all made synonyms of *M. fluviatilis*, now *Ephydatia fluviatilis*. In some cases illustrations or descriptive statements indicate clearly enough which of the two species is involved, but often one can not tell. *E. fluviatilis* has birotulate gemmule-spicules with shafts longer than the diameter of the rotules, and the skeleton spicules uniformly smooth; while *E. mülleri* has the shafts usually shorter than the diameter of the rotules, and the skeleton spicules varying from distinctly spined or sparsely micro-spined to nearly or quite smooth. Distinctly spined and smooth spicules are often associated in the same specimen and in different ratios in different specimens. The gemmule walls of *E. mülleri* not infrequently include two or even three layers of birotulate spicules, while those of *E. fluviatilis* uniformly have but a single layer. Potts erroneously assumed that the distinction between these two species was based merely on the last-mentioned difference, and since the appearance of more than a single layer in the former species is not a constant character, he decided against the validity of the species.

Another source of error involving North American species, which is of less consequence because less confusing, has arisen from the description by Hilgendorf in 1882 of a Japanese sponge as variety *japonica* of *E. fluviatilis*. Judging from the description, this is nothing other than the form of *E. mülleri* in which the skeleton spicules are smooth. Among the United States National Museum specimens examined by Annandale was one from the Potomac River which he listed in 1910 as *E. japonica*, recognizing this form as a distinct species. In 1916 after a study of Japanese sponges among which were the various forms of *E. mülleri*, he treated the *japonica* form as a variety of *E. mülleri*. The writer believes that there is not sufficient basis for giving it even the rank of a variety. It is simply a very common variant form of a highly variable species. In the original description of *E. mülleri* the skeleton spicules were described as spined, but by various students of the species in England, Germany, and Austria the extremely variable condition has been well known and frequently mentioned. The specimens of this species in the writer's collections from different parts of Michigan, from high mountain-lakes of Colorado, and from Montana, indicate that those with smooth or nearly smooth skeleton-spicules and those with spined spicules are similarly distributed; and also that the same body of water may contain both of these kinds of specimens, and still others with spined and smooth spicules associated in the same skeleton fascicles. Among the Colorado specimens, those with spined skeleton-spicules are more frequent

than those with smooth ones, but the distribution is similar; while in the Michigan material, specimens with smooth or nearly smooth skeleton-spicules are most frequent. *E. fluviatilis* has a distribution similar to that of *E. mülleri*, but is less abundant.

ILLINOIS SPECIES

In 1883 Henry Mills, of Buffalo, New York, found in the Calumet River, near Chicago, a sponge which he afterwards described under the name *Pleiomeyenia calumeticus*, but which evidently was the form of *Ephydatia mülleri* having smooth skeleton-spicules. In the same paper (1884a) he mentions finding *Carterius tubispermia* in Illinois.

Mills read before the State Microscopical Society of Illinois, on May 27, 1887, a paper on fresh-water sponges which recorded eight species found in the state, and which was published in full in an issue of a local newspaper. Since it contains the earliest definite record of the occurrence in the state of some of the species mentioned, that part of the paper which describes the localities and gives the details of the collecting activities is here reproduced with a few typographic errors corrected. It appeared under the general heading, "Fresh Water Sponges", and with the following subheadings: "Paper by Henry Mills, of Buffalo, read before the Microscopical Society"; "Earliest Mention of this Species of Infusoria and Difficulty of their Classification"; "Record of a Scientific Party which lately Explored some of the Illinois Lakes".

On the 20th of September, 1886, a party consisting of B. W. Thomas and W. H. Summers, members of the State Microscopical Society, Chicago, and the writer made an effort to explore some of the lakes in Illinois, north of Chicago, with sanguine expectation of being able to add something to our list of genera and species of these and other microscopic objects; for, although the two Chicago gentlemen searched principally for Diatomaceous material, the writer gratefully acknowledges valuable help from them in the search for the objects of his special pursuit. We left Chicago by the afternoon train on the Chicago and Northwestern Railway, arriving at McHenry, McHenry County, in time to prepare for an early start up the Fox River in the morning. Each of the party had his boat, and collecting apparatus, and those who felt like using the oars did so, while those who felt so inclined secured others to do the hard work. It was a cloudy and rather cool morning, and by the time we reached "Dutchman's Slough," which is the outlet of a small sluggish stream or creek three and one-half miles north of McHenry, there was a drizzling rain, which threatened to dampen the enthusiasm of the party; but as it did not last long, we were soon ready for work. Although not immediately successful, there was enough enchantment in the spot and its surroundings to inspire us with confidence, and in a short time we reached a place in the slough where the sponge could be hauled by the drags, with the weeds to which it was attached in large handfuls. The weeds or algae upon which the sponge grew consisted of a species of *Utricularia*, and *Anacharis canadensis* (both of microscopic interest), and some others not recorded. Unfortunately the sponge, on examination at home with the microscope, proved to be mostly immature, containing but few statoblasts, but enough to determine the species as mostly *Carterius tubispermia* Mills; *Meyenia fluviatilis* and *Meyenia Calumetica* Thomas. But in the interest of science the spot should be remembered, that future investigators may be benefited at least to the extent of our discoveries in this interesting locality. Other micro-

scopical material, especially Diatomaceae, was present in great abundance. The sponge was beautifully clean, of a bright, buff color, a small piece or perhaps a separate sponge the size of a small hickory nut being attached to every frond of the Utricularia. After obtaining as much of this as we could care for, besides other material, we started up the river, passing through lakes Pistakee and Nippersink into Fox Lake, resting for the night at "Hotel Sayles," situate on Hickory Point, the dividing ridge between Lake Nippersink and Fox Lake. The following morning we found only some Diatomaceous material, and soon pushed off in the direction of Cedar Lake, which is about four miles from our hotel and two miles from Fox Lake. Here the wind, from an approaching storm, so ruffled the water as to make all attempts at collecting futile. On our return to the neighborhood of the hotel we succeeded in finding a large quantity of *Spongilla lacustris*, which well repaid us for the disappointment in the earlier part of the day.

This sponge, unlike the former, was of a bright emerald green, growing in long digitate processes and branches, attached to weeds or stones in about three feet of water. Nothing could exceed the beauty of this sponge seen growing in the sunshine when the water was quite still. The vital action of the sponge could be seen, causing the gentle waving motion which is described as occurring in marine sponges. Had we made this gathering six weeks later in the season it would have been a real treasure, the statoblasts, which are now few, would by that time have been present in great abundance. The same party has made several excursions to the streams and sloughs south of Chicago. In the Calumet River, at Blue Island, fragments of sponges and some rare algae were found. The sponges consisted of *Meyenia fluviatilis* and *Spongilla lacustris*, while the algae most noticeable were fine specimens of *Chara* and *Nitella*. These, for want of large jars, could not be preserved. In 1883 and in 1886 we visited the Cummins Bridge, over the Calumet River near Calumet Lake, and on both occasions were well rewarded with rich gatherings of sponges, Diatomaceae and other microscopic objects. Among these was a quantity of the Polyzoan *Idae*, the winter eggs of which are similar in physiological history to the statoblasts of the fresh-water sponge. Among the sponges found was *Meyenia fluviatilis*, one peculiar variety of which was described and named some five years ago by Mr. B. W. Thomas as *Meyenia calumetica*; a small piece of *Heteromeyenia argyrosperma*, Potts; *Carterius tubisperma*, Mills; *Carterius latitenta*, Potts, and a variety of *Heteromeyenia repens*, Potts; also a variety of *Spongilla fragilis*, Leidy, including one known as *Spongilla fragilis* variety *calumeti*.

These statements are made with the hope that they will encourage others of like tastes and inclinations to make further search in this neglected, but interesting branch of study.

I know of no more promising field of research for the naturalist, whether for sponges, diatoms or other microscopical material, than the chain of small lakes and swamps in McHenry County, and the region extending from ten to thirty miles south and southwest of Chicago.

It is practically certain that some of the specimens which were identified in the above report as *Meyenia fluviatilis* or one of its varieties, were actually *Ephydatia mülleri*, but there is considerable probability that *E. fluviatilis* was also represented.

Asteromeyenia radiospiculata is reported from Granite City, Illinois, by Annandale in a brief paper (1911) in which he created the genus *Asteromeyenia* to receive two North American species which have radiate dermal spicules, and gemmule spicules of two or more distinct classes.

Sponges collected by R. E. Richardson, and others, in the Illinois River at various locations, in connection with certain investigations of the

Illinois State Laboratory of Natural History in 1912—1914, have been identified by the writer as follows, the locality records being added: *Spongilla fragilis* was generally distributed from Starved Rock, near La Salle, to Meredosia at least; *Ephydatia fluviatilis* was found in sloughs near Havana; *Carterius latitenta* was abundant from Starved Rock to Copperas Creek; *Asteromeyenia radiospiculata* was found at Hardin and Grafton; *Trochospongilla leidyi* was abundant from La Salle to Hardin; and one specimen of *T. horrida* was found at Starved Rock. A second specimen of the last-named species was collected by A. A. Hinkley in the southern part of the state in the Big Muddy River near Waltonville in 1914. As far as is known to the writer the above are the first records for *T. horrida* in North America.

Ephydatia crateriformis and *Spongilla fragilis* have been collected in the Sangamon River, at places a few miles west of Urbana, but the stream is too muddy to permit the development of an extensive sponge fauna. Collections from ponds and streams of the drainage basin of Salt Fork, a branch of the Vermilion River, at various places from Urbana to Muncie (which is about twenty miles farther east), have contained *Spongilla fragilis*, *Ephydatia fluviatilis*, *E. crateriformis*, and *Carterius latitenta*. The first- and last-named species are the most abundant. The total of twelve species already recorded should be increased somewhat when careful collecting has been done in other parts of the state.

ADDITIONAL NORTH AMERICAN RECORDS

Collections received from various sources have made it possible to list species from a few states from which sponges had not been previously reported, and to add species to the lists previously reported from several other states. Reference to some of these new records has been made in the key to sponges contained in Ward and Whipple's Fresh-Water Biology. The new records are indicated in the distribution table (page 17) by the letter S. The United States National Museum has several specimens which add previously unrecorded species to the lists of each of seven states, and these are indicated in the table by the letter U. A brief summary of the new records and the data of the collections on which they are based follows. The order of sequence in presenting the items is determined by their geographic distribution from east to west, and from north to south.

Spongilla lacustris in a collection made by A. O. Gross in the vicinity of Brunswick, Maine.

Spongilla igloziformis and *Tubella pennsylvanica* in a collection made by Miss Elizabeth Bodfish from a pond near Palmer, Massachusetts.

Ephydatia crateriformis in a collection of the United States National Museum, from the Potomac River at Washington, D. C., and *Spongilla lacustris* from Pomonkey Creek, Maryland.

Heteromeyenia ryderi in a collection of the above-named museum, from the Dismal Swamp in Virginia; and *Ephydatia mülleri*, from Dyke, Virginia.

Ephydatia crateriformis in a collection of the same museum, from the mouth of the Shiawassee River in Michigan.

Heteromeyenia repens in a collection of the same museum, from the outlet of Lost Lake, in Indiana.

Trochospongilla leidy in a collection of the same museum, from Frankfort, Kentucky.

Tubella pennsylvanica in a collection made by A. T. Evans, near Rhinelander, Wisconsin; and *Carterius latitenta*, one gemmule, in débris from the bottom of Lake Mendota, Wisconsin.

Spongilla fragilis in a collection from N. M. Grier, made in Lake Pepin, Minnesota; and *S. lacustris* in a collection made by H. V. Heimbürger near St. Paul, Minnesota.

Spongilla fragilis in a collection from the United States Fisheries Station at Fairport, Iowa.

Spongilla fragilis and *S. lacustris* in a collection made by Dr. Mary T. Harman near Manhattan, Kansas; and *Carterius tubisperma* in a collection of the United States National Museum, from Goodland, Sherman county, Kansas.

Spongilla lacustris and *Ephydatia mülleri* (typical form with spined skeleton-spicules) in a collection made by Miss Bessie R. Green from a pond near Flathead Lake in Montana.

Spongilla fragilis and *S. lacustris* in a collection made by Professor S. A. Forbes in the year 1890 in Yellowstone Park, Wyoming.

Spongilla fragilis, *S. lacustris*, *Ephydatia fluviatilis*, and *E. mülleri* in collections by the writer in the vicinity of Tolland, Colorado, in the year 1916. Sponges were found in eleven of the thirty ponds and lakes examined and are probably contained in others. Apparent absence was probably due in some instances to the very brief time allowed for making collections. *Ephydatia fluviatilis* was found only in Smartweed Lake, which has an altitude of about 8,575 feet. *Spongilla fragilis* was found in ten bodies of water with altitudes ranging from 8,100 to 10,580 feet. *S. lacustris* was collected in seven ponds and lakes, with altitudes of 8,850 to 10,580 feet, and *Ephydatia mülleri* in four of the same. Lower Crater Lake (alt. 10,580 ft.), yielding the three species last named, was the highest of the bodies of water in which sponges were found during the summer of 1916. In August, 1913, *Spongilla lacustris* was collected in the same vicinity, in West Forest Lake, which has an altitude of about 10,800 feet.

Spongilla lacustris in a collection made by H. L. Osterud in Lake Washington, near Seattle, Washington.

Carterius tubisperma in a collection of the United States National Museum, from Fresno, California.

Spongilla lacustris has recently been received from Dr. F. Johansen, who collected it during the summer of 1920 in a pond on an island in James Bay, Canada, latitude about $52\frac{1}{2}^{\circ}$ N.

Specimens without gemmules, which are probably *Spongilla lacustris*, were collected by Professor H. B. Ward in July, 1919, in Long Lake, in the Copper River Basin, Alaska, latitude $61^{\circ} 25'$ N.

Major George H. Conklin, M. D., of Superior, Wisconsin, who was an enthusiastic collector and student of fresh-water sponges about thirty years ago, has furnished the following list of species found by him during the years 1890, 1891, and 1892 at various places in Douglas county, in the northwestern part of Wisconsin: *Spongilla fragilis*, *S. lacustris*, *S. igloviformis*, *Ephydatia fluviatilis*, *E. crateriformis*, *Heteromeyenia argyrosperma*, *Tubella pennsylvanica*, and *Carterius tubisperma*. Unfortunately his collections were destroyed by fire some years ago. It is probable that the name *Ephydatia fluviatilis* was applied to both *E. fluviatilis* and *E. mülleri* in accordance with the practice of Potts and other American workers of the time. The only record differing from what one would expect, considering the records in neighboring states, is that of *Spongilla igloviformis*, this being the only report of it west of the Alleghany Mountains.

TABULAR PRESENTATION OF DISTRIBUTION DATA

Records of the North American species of fresh-water sponges and the states from which they have been reported in various scientific publications are indicated in the following table by an asterisk. As stated on preceding pages, new records in this paper are indicated by the letter S; records from the paper by Mills, quoted on preceding pages and not otherwise listed, are indicated by the letter M; unpublished records based on specimens in the United States National Museum are indicated by the letter U; and records of species in Wisconsin, furnished by Dr. Conklin, and not otherwise listed, are indicated by the letter C. In a few cases in which *Ephydatia fluviatilis* is reported, there is nothing to indicate that the specimens may not actually have been *E. mülleri*, the record is therefore indicated by an interrogation point under each name.

It is not improbable that a few published records have been omitted from the table, since several papers dealing with the subject have not been accessible, but this is intended to serve only as a "report of progress."

	<i>Sp.</i>	<i>fragilis</i>	<i>lacustris</i>	<i>igloformis</i>	<i>aspinosa</i>	<i>heterosclerifera</i>	<i>wagneri</i>	<i>Eph. fluviatilis</i>	<i>mülleri</i>	<i>crateriformis</i>	<i>everetti</i>	<i>baileyi</i>	<i>millsii</i>	<i>subdivisa</i>	<i>robusta</i>	<i>Het. argyrosperma</i>	<i>repens</i>	<i>tyderi</i>	<i>Car. latitenta</i>	<i>leucosperma</i>	<i>tubisperma</i>	<i>Ast. radiospiculata</i>	<i>plumosa</i>	<i>Tro. leidy</i>	<i>horrida</i>	<i>Tab. pennsylvanica</i>	<i>Sp. mackayi</i>	<i>novae terrae</i>	<i>Eph. fluv. mexicana</i>	<i>Het. pictonensis</i>	<i>macouni</i>	<i>Dos. palmeri</i>	
Me.		S																															
N. H.																	*																
Mass.			*	S						*	*							*			*						S						
N. Y.			*	*	*					*	*	*					*	*	*	*	*												
N. J.			*	*	*	*											*	*	*	*	*												
Penn.			*	*						?	*	*					*	*	*	*	*												
Md. & D. C.			S							*	S																						
Va.				*						S									U														
Fla.		*				*		*					*	*	*			*									*						
Mich.		*	*					*	*	U							*	*	*	*	*						*						
Ohio		*	*					?	?	*									*	*	*	*					*						
Ind.		*						?	?	*							*	S	*	*	*												
Ky.		*																															
Wis.		*	*	C				?	?	*							C		S	C							C						
Minn.		S	S																														
Ill.		M	M					*	*	S							M	M		*	*				S	S							
Iowa		S	*					*									*			*	*												
Kan.		S	S																	U													
La.																																	
Tex.																																	
Mont.		*	S					S																									
Wyo.		S	S																														
Col.		S	S					S	S																								
Wash.		S																															
Cal.															*					U													
N. F.		*	*					*																			*	*	*	*			
N. S.		*	*					*	*	*							*	*									*	*	*	*			
Can.		*	*					?	?								*																
Sable Isl.																																*	
Alaska		S																															
Mexico								*																						*	*		
Europe		*	*					*	*	*	*			*		*	*	*		*					*	*	*	*					
Asia		*	*					*	*	*											*				*	*	*						

North American species which are extra-limital to the United States

North American species which are
extra-limital to the United States

LITERATURE DEALING WITH FRESH-WATER SPONGES OF NORTH AMERICA

Adams, C. C.

1909. An ecological survey of Isle Royale, Lake Superior. Rep. Mich. Geol. Surv., 1908. (Sponges, p. 249-250.)

Annandale, N.

1909. Fresh-water sponges in the collection of the United States National Museum.—Part II. Specimens from North and South America. Proc. U. S. Nat. Mus., 37 : 401-406.
1910. Fresh-water sponges in the collection of the United States National Museum.—Part IV. Note on the fresh-water sponge, *Ephydatia japonica*, and its allies. Idem, 38 : 649-650.
1911. Fresh-water sponges in the collection of the United States National Museum.—Part V. A new genus proposed, with *Heteromeyenia radiospiculata* Mills as type. Idem, 40 : 593-594.

Baker, F. C.

1918. The productivity of invertebrate fish food on the bottom of Oneida Lake, with special reference to mollusks. Tech. Pub. No. 9, N. Y. State Coll. For. (Sponges, p. 186-187.) Syracuse.

Bowerbank, J. S.

1863. A monograph of the Spongillidae. Proc. Zool. Soc. London, 1863, p. 440-472.
1864. Description of two American sponges. Can. Nat. and Geol. (n. s.) 1 : 304-307.

Carter, H. J.

1881. On Spongiophaga in Spongilla. Ann. Mag. Nat. Hist. (5) 8 : 222.
1881a. On *Spongiophaga pottsi*. Ann. Mag. Nat. Hist. (5) 8 : 354-362.
1882. Form and nature of the cirrous appendages on the statoblast of *Carterella latitenta* Potts, etc., originally designated *Spongiophaga pottsi*. Ann. Mag. Nat. Hist. (5) 9 : 390-396.
1885. Note on *Spongilla fragilis*, Leidy, and a new species of *Spongilla* (*Mackayi*) from Nova Scotia. Ann. Mag. Nat. Hist. (5) 15 : 18-20.
1885a. On a variety of the fresh-water sponge, *Meyenia fluviatilis*. Ann. Mag. Nat. Hist. (5) 15 : 453-456.
1885b. On a variety of the fresh-water sponge, *Meyenia fluviatilis*, from Florida. Ann. Mag. Nat. Hist. (5) 16 : 179-181.

Clark, H. James

1871. The American Spongilla, a craspedote, flagellate infusorian.
Am. Jour. Sci. and Arts. (3) 2 : 426-436.

Dawson, G. M.

1878. On some Canadian species of Spongilla. Can. Nat. (n. s.)
8 : 1-5.

Edwards, Arthur M.

1896. Sponges considered microscopically. Am. Month. Micr. Jour.
16 : 379-381.

Evermann, B. W., and Clark, H. W.

1920. Lake Maxinkuckee—a physical and biological survey. 2 vol.
Pub. by Dept. Conserv. Indiana. (Sponges, 2 : 103-104.)

Forbes, S. A.

1893. A preliminary report on the aquatic invertebrate fauna of
the Yellowstone National Park, Wyoming, and of the
Flathead Lake region of Montana. Bul. U. S. Fish Comm.
11 : 207-258.

Hankinson, T. L.

1916. Observations on the Fishes of Houghton county, Michigan.
Pub. 20, Biol. Ser. 4, Mich. Geol. and Biol. Surv.
(Sponges, p. 17.)
1916a. Results of the Shiras expeditions to Whitefish Point, Michi-
gan: fishes. Idem. (Sponges, p. 118.)

Kellicott, D. S.

1891. The Mills collection of fresh-water sponges. Bul. Buffalo
Soc. Nat. Sci. 5 : 99-104.
1897. Preliminary report on the fresh-water sponges of Ohio.
5th Ann. Rep. Ohio State Acad. Sci., p. 50.

Kirsch, A. M.

1909. Fresh-water sponges and particularly those of the United
States. Midland Naturalist, Notre Dame, Ind., 1 : 29-38.
1909a. Carterius both a synonyme and homonyme. Idem, 1 : 60.

Kofoed, C. A.

1899. The plankton of Echo River, Mammoth Cave. Trans. Am.
Micr. Soc. 21 : 113-126.
1908. Plankton studies. V. The plankton of the Illinois River,
1894-1899. Part II. Constituent organisms and their
seasonal distribution. Bul. Ill. State Lab. Nat. Hist. 8 :
1-361. (Porifera on p. 132.)

Landacre, F. L.

1902. Sponges and bryozoans of Sandusky Bay. Ohio Nat. 1 : 96-97.

Leidy, Joseph

1851. *Spongilla fragilis*. Proc. Acad. Nat. Sci. Phil. 5 : 278.

Lockwood, S.

1885. *Heteromeyenia ryderi*. Jour. N. Y. Micr. Soc. 1 : 37-40.

MacKay, A. H.

1885. Notes on Nova Scotia fresh-water sponges. Proc. Trans. Nova Scotia Inst. Nat. Sci. 6 : 145-148.
 1885a. Notes on the fresh-water sponges of Nova Scotia. Idem, 6 : 233-240.
 1885b. Organic siliceous remains in the lake deposits of Nova Scotia. Can. Rec. Sci. 1 : 236-244.
 1886. New fresh-water sponges from Nova Scotia and Newfoundland. Idem, 2 : 19-22.
 1887. The fresh-water sponges of Newfoundland. Idem, 2 : 497-499.
 1889. Fresh-water sponges of Canada and Newfoundland. Trans. Roy. Soc. Can. 7 : 85-95.
 1900. A fresh-water sponge from Sable Island. Proc. Trans. Nova Scotia Inst. Nat. Sci. 10 : 319-322.

Mills, H.

1880. Fresh-water sponges. Am. Jour. Micr. and Pop. Sci. 5 : 125-132.
 1881. New fresh-water sponges. Idem, 6 : 30-31.
 1882. Notes on the Spongiellae of Buffalo. Bul. Buffalo Soc. Nat. Sci. 4 : 57-60.
 1882a. Fresh-water sponge. Proc. Am. Soc. Micr. 1882, p. 209-216.
 1884. Serial arrangement of birotulate spicules in statoblasts of American sponges. Am. Monthly Micr. Jour. 5 : 41-42.
 1884a. Thoughts on the Spongiidae, with reference to the American sponges of the fresh-water group, with some account of them in detail. Proc. Am. Soc. Micr., 1884, p. 131-147.
 1887. Notes on the genus Carterius, formerly Carterella, of the fresh-water sponges. Microscope, 7 : 161-164.
 1887a. Hints on the fresh-water sponges. Idem 7 : 294-297.
 1888. A new fresh-water sponge. *Heteromeyenia radiospiculata* n. sp. Idem, 8 : 52-53.
 1889. Fresh-water sponges. Jour. Micr. and Nat. Sci. (n. s.) 2 : 82-85.

Muttkowski, R. A.

1918. The Fauna of Lake Mendota—A qualitative and quantitative survey with special reference to the insects. *Trans. Wis. Acad. Sci. Arts, Let.* 19: 374-482. (Porifera on p. 388.)

Needham, J. G.

1908. Report Entomologic Field Station conducted at Old Forge, N. Y., in the summer of 1905. *N. Y. State Mus. Bul.* No. 124. (Sponge report, p. 163.)

Potts, Edward

1880. Fresh-water sponges of Fairmount Park. *Proc. Acad. Nat. Sci. Phil.* 1880, p. 330-331.
1881. On fresh-water sponges. *Idem*, 1880, p. 356-357.
- 1881a. Some new genera of fresh-water sponges. *Idem*, 1881, p. 149-150.
- 1881b. A new form of fresh-water sponge. *Idem*, 1881, p. 176.
1882. The genus *Carterella* vs. *Spongiophaga* Pottsi. *Idem*, 1881, p. 460-463.
- 1882a. Three more fresh-water sponges. *Idem*, 1882, p. 12-14.
- 1882b. Sponges from the neighborhood of Boston. *Idem*, 1882, p. 69-70.
1883. Fresh-water sponges, what, where, when, and who wants them. *Bul. U. S. Fish Comm.* 3 : 389-391.
- 1883a. Our fresh-water sponges. *Am. Nat.* 17 : 1293-1296.
1884. Fresh-water sponges as improbable causes of the pollution of river-water. *Proc. Acad. Nat. Sci. Phil.* 1884, p. 28-30.
- 1884a. Some modifications observed in the form of sponge spicules. *Idem*, 1884, p. 184-185.
- 1884b. On the wide distribution of some American sponges. *Idem*, 1884, p. 215-217.
- 1884c. On the minute fauna of Fairmount Reservoir. *Idem*, 1884, p. 217-219.
1885. A new fresh-water sponge from Nova Scotia. *Idem*, 1885, p. 28-29.
- 1885a. A fresh water sponge from Mexico. *Am. Nat.* 19: 810-811.
- 1885b. Fresh-water sponges from Mexico. *Proc. U. S. Nat. Mus.* 8 : 587-589.
1886. Fresh-water sponges from Newfoundland: A new species. *Proc. Acad. Nat. Sci. Phil.* 1886, p. 227-230.
1887. Fresh-water sponges. A monograph. *Idem*, 1887, p. i-iv and 157-279 (Reprint.)
1889. Report upon some fresh-water sponges collected in Florida by Jos. Willcox, Esq. *Trans. Wagner Inst. Phil.* 2 : 5-7

1890. Fresh-water sponges. I. What they are not. *Microscope*, 10:140-143. II. What they are. *Idem*, 10:161-163. III. What they are. The spicules. *Idem*, 10:193-196. IV. How to find and gather them. *Idem*, 10:257-263. V. The determination of species. *Idem*, 10:307-310.
1918. The sponges (Porifera). Chapter X in Ward and Whipple's *Fresh-Water Biology*. New York.
- Priest, B. W.
1884. Statoblasts of the fresh-water sponges. *Am. Monthly Micr. Jour.* 4:208-213.
- Shelford, V. E.
1913. Animal communities in temperate America as illustrated in the Chicago region. (Sponges, p. 153.) Univ. Chicago Press, Chicago.
- Smith, F.
1918. A new species of *Spongilla* from Oneida Lake, New York. *App., Tech. Pub. No. 9*, N. Y. State Coll. For. p. 239-242.
- Smith, F., and Green, Bessie R.
1916. The Porifera, Oligochaeta, and certain other invertebrates in the vicinity of Douglas Lake, Michigan. *Rep. Mich. Acad. Sci.* 17:81-84.
- Stedman, J. M.
1891. The nervous system of the fresh-water sponge. *Proc. Am. Soc. Micr.* 13:77-78.
- Waller, J. G.
1897. The president's address. *Jour. Quek. Micr. Club.* (2) 6:333-344.
- Ward, H. B., and Whipple, G. C.
1918. *Fresh-water biology*. (Sponges, p. 301-315.) New York.
- Washburn, F. L.
1898. A preservative for fresh-water sponge. *Jour. Applied Micr.* 1:73.
- Weltner, W.
1895. *Spongillidenstudien*. III. Katalog und Verbreitung der bekannten Süßwasserschwämme. *Arch. f. Naturg.* 61:114-144.

STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION
DIVISION OF THE
NATURAL HISTORY SURVEY
STEPHEN A. FORBES, Chief

Vol. XIV.

BULLETIN

Article III.

A Study of the Malarial Mosquitoes
of Southern Illinois

II. OPERATIONS OF 1920

BY

STEWART C. CHANDLER



PRINTED BY AUTHORITY OF THE STATE OF ILLINOIS

—
URBANA, ILLINOIS

November, 1921

SCHNEPP & BARNES, PRINTERS, SPRINGFIELD, ILL.

52443—1,200

ARTICLE III.—*A Study of the Malarial Mosquitoes of Southern Illinois. II. Operations of 1920.** BY STEWART C. CHANDLER.

INTRODUCTION

The mosquito survey of southern Illinois, which was begun by the author in the spring of 1918, has been carried forward during the season of 1920 at Herrin, Williamson county, and vicinity. The object of the work, as fully explained in a former article of the Natural History Survey Division,* is to locate the places which breed mosquitoes, to point out what types of location are especially favorable to the production of the malaria mosquitoes, and to increase our knowledge of the seasonal occurrence of all mosquito species to be found in southern Illinois. It is hoped that these articles will provide data of use to citizens of communities interested in a reduction of malarial disease through a control of the mosquitoes transmitting it. It is planned to continue the survey, each year in a different locality typical of some considerable area, so that eventually all types will be covered.

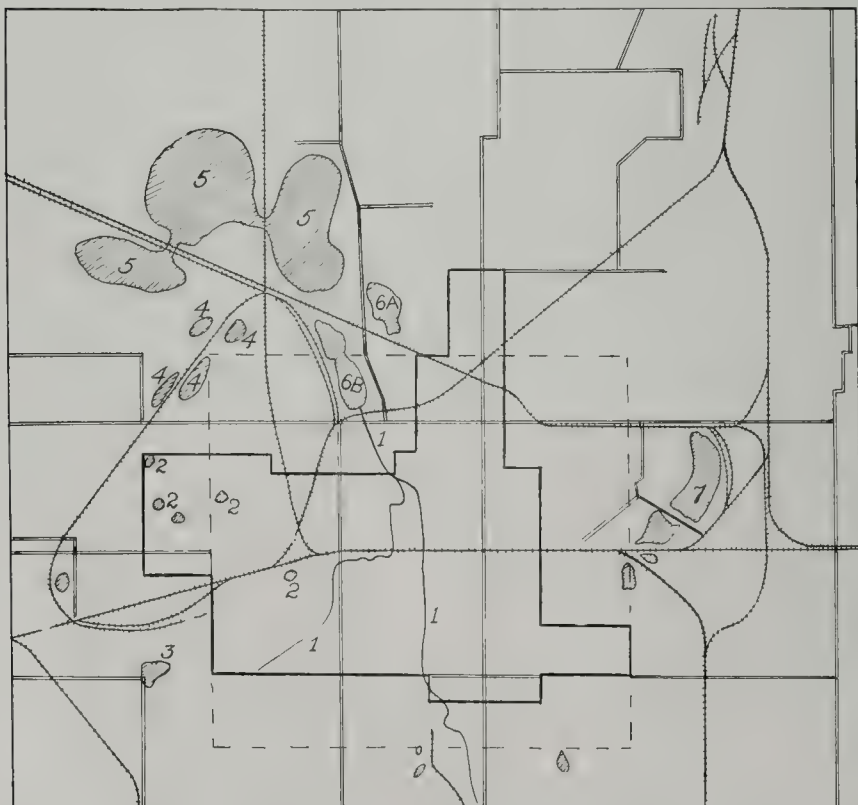
Before describing the work of the season, it is well to recall a few fundamental facts about mosquitoes and the relation between them and malaria. It is especially important to remember that some body of water, either temporary or permanent, is necessary to the development of the mosquito. Of the four stages through which this insect passes in its life cycle, egg, larva, pupa, and adult, the first three are entirely aquatic. The adult mosquito lays its eggs upon the surface of the water, or failing to find any water it may die without depositing any eggs. The common wigglers or wiggle-tails which hatch from these eggs pass their existence in the water, feeding on the minute organisms which they find there, until they emerge as adults, this entire process requiring from one to three weeks. The dependence of the malarial organism upon the mosquito needs no discussion here, except merely to state that malaria is transmitted to man only through the bite of certain species of mosquitoes belonging to the genus *Anopheles*. These mosquitoes are called the Anopheline or malarial mosquitoes to distinguish them from the Culicine species, which do not carry the disease.

DESCRIPTION OF THE BREEDING PLACES AT HERRIN

The situation at Herrin is typical of much of the mining territory in southern Illinois. The town was started at a point between three coal mines and has spread in all directions up to the edges of the mine properties. Close to each mine two kinds of water are to be found, one in ponds cared for by the mining company and used for boilers and washers.

* Article XI, volume 13. *A Study of the Malarial Mosquitoes of Southern Illinois. I. Operations of 1918 and 1919.* By Stewart C. Chandler.

and the other the waste water from the mines which is allowed to run off where it will as long as it does not contaminate the other source. There are a few sink-holes in the west part of Herrin, also characteristic of a mining area because they are probably caused by the sinking of the ground over a part of the mine which has been worked out and abandoned. Just to the northwest of Herrin is a woods swamp, which in rainy seasons covers an area of about half a square mile. Low, swampy, wooded areas are fairly common in the mining sections of Williamson and Franklin counties; and in this case the water in the swamp is kept replenished by waste water from the mines.



In going carefully over the town and the territory immediately surrounding it I found eight breeding places, or series or types of breeding places—including those I have classed as domestic—from which the mosquitoes to be found in Herrin might be expected to come. All but the latter class are numerically indicated on the accompanying map, and a brief characterization of all of them follows:

No. 1. An open drain through town, known as the 14th St. ditch. This ditch is fed quite largely by waste water from the mines supplemented by small tributaries which carry off the rains and natural surface water.

No. 2 (Fig. 1). Sink-holes to be found in the west part of Herrin, the formation of which has already been described.



FIG. 1. Sink-hole, West Herrin; produces very few mosquitoes.



FIG. 2. Woodland pool, north edge of Herrin; a prolific breeder of malarial mosquitoes

No. 3 (Fig. 2). The mine pond at Sunnyside, in the southwest corner of Herrin.

No. 4. A series of woodland pools to the northwest along a railroad track, and partially formed by the railroad embankment. This track is a feeder to one of the mines and is much frequented by miners, especially when going to fish in the ponds of that vicinity.

No. 5. A woods swamp to the northwest of Herrin, described above.

No. 6. Mine ponds north of Herrin. The main pond, marked A on the map, is used for the boilers and washers, and the other, marked B, is a swampy area overgrown with cattails and fed by waste water from the 17th St. ditch.

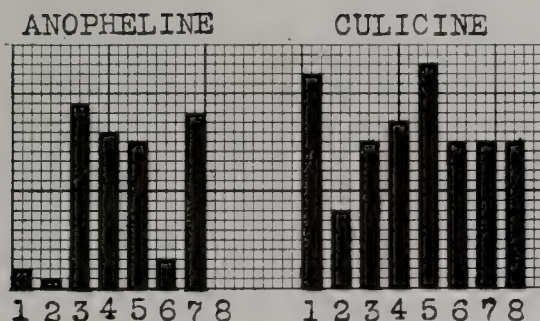
No. 7. A series of mine ponds to the east of town.

No. 8. Domestic places, such as tin cans, rain-water barrels, wells, and reservoirs.

THE PRODUCTION OF MOSQUITOES

Monthly inspections were made at each of the eight series of breeding places, and a record of the abundance of mosquito wigglers was kept. Larvae and pupae were collected and reared to the adult stage in the author's insectary at Carbondale. The species were later determined by Dr. C. P. Alexander, of the Natural History Survey. The determinations of two species supposedly foreign to this region and one new species were corroborated by Dr. Harrison G. Dyar, of the United States National Museum.

The accompanying table (Record of Mosquito-breeding at Herrin, 1920) shows the monthly abundance of mosquitoes, both Anopheline and Culicine, in the eight different breeding places watched during the season. It will be noticed that six terms are used in this table to indicate absence or grades of abundance, namely, none, very few, few, fair numbers, many, and very many. In order to give a numerical value to these records, none is represented by a cipher (0), very few by 1, few by 2, fair numbers by 3, many by 4, and very many by 5. These figures are inserted in the table at the right of the terms to which they apply, thus making it possible to secure totals convenient for purposes of comparison. The totals for each month show the relative danger, throughout the season, of becoming infected through the bite of the Anopheline mosquitoes; and the totals for each breeding place may be useful in distinguishing the types of places which produce the most mosquitoes. The mosquito production is shown more clearly by the following diagram in which the breeding-place totals from the table are represented by the heights of the columns, the eight columns representing the eight breeding places. Both the Anopheline and the Culicine mosquito records are shown on the diagram for purposes of comparison.



A mere glance at the table (p. 28) or the diagram will show that there is a great difference in the breeding places in respect to their production of mosquitoes during the season. It is very evident that an abundance of Anopheline mosquitoes may be produced in a place in which few Culicine species are bred, and *vice versa*. It may be difficult to account for these variations in the numbers of mosquitoes produced in different situations, but a study of conditions at Herrin may help to distinguish the types of places that are most dangerous.

COMPARISON OF BREEDING PLACES

No. 1, an open ditch, proved to be of little importance for the production of malarial mosquitoes, but of considerable importance for the other type. In the main channels of this ditch the waste water from the mines seemed to prevent mosquito development, and (a very important fact) the edges of the ditch were clean, with little or no overhanging vegetation to furnish protection to the mosquito larvae. Those found were in the small feeders or tributaries; and in most cases contamination of the water in them by the filth of the street made conditions unfavorable for *Anopheles* larvae.

No. 2, a series of sink-holes, produced relatively few mosquitoes, either Anopheline or Culicine. Many of the pools dried up wholly or partially, the receding waters leaving edges exposed and unprotected, so that predaceous enemies could keep the mosquito larvae and pupae down to a minimum.

Nos. 3, 4, 5, and 7 all contained considerable water, had much grass or weeds along their margins, and appeared to contain enough suitable food for the development of malarial mosquitoes. No. 3 is an especially typical breeding place for them.

No. 6 did not seem to be favorable to the production of Anopheline mosquitoes. None of either kind were found in Part B, which contained much waste water from the mines, and but a few in Part A, which from its character might be expected to contain *Anopheles* larvae.

No. 8, including all sorts of domestic containers of water, produced no Anopheline mosquitoes whatever, but was responsible for some Culi-

RECORD OF MOSQUITO-BREEDING AT HERRIN, 1920

ANOPHELINE (MALARIA-CARRYING) MOSQUITOES

Breeding places	April	May	June	July	August	Sept.	Oct.	Nov.	Breed- ing place totals.
1. Open ditch	None	0	Few	2	None	0	None	0	2
2. Sink-holes	None	0	None	0	None	0	Very few	1	1
3. Mine pond	None	0	None	0	Very many	5	Many	4	19
4. Woodland pools	None	0	Fair Nos.	3	Many	4	Fair Nos.	3	16
5. Woods swamp	None	0	Fair Nos.	3	Many	4	Fair Nos.	3	15
6. Mine ponds	None	0	None	0	None	0	Fair Nos.	3	3
7. Mine ponds	None	0	Fair Nos.	3	Many	3	Fair Nos.	3	18
8. Domestic places	None	0	None	0	Fair Nos.	3	Fair Nos.	3	0
Totals for each month	0	0	11	13	16	15	16	3	74
CULICINE (NON-MALARIA-CARRYING) MOSQUITOES									
1. Open ditch	None	0	Few	2	Very many	5	Very many	5	22
2. Sink-holes	None	0	None	0	Few	2	Few	2	8
3. Mine pond	None	0	None	0	Many	4	Fair Nos.	3	15
4. Woodland pools	Many	4	Fair Nos.	3	Fair Nos.	3	Few	2	17
5. Woods swamp	None	0	Fair Nos.	3	Fair Nos.	3	Very many	5	23
6. Mine ponds	None	0	Many	4	Fair Nos.	3	Few	2	15
7. Mine ponds	None	0	Fair Nos.	3	Very many	5	None	0	15
8. Domestic places	None	0	None	0	Very many	5	Very many	5	15
Totals for each month	4	8	14	25	30	28	21	0	130

cines. This corroborates statements made by many observers of mosquito life, that the malaria-carrying mosquitoes do not by choice breed in water found about the habitations of man.

MALARIA IN HERRIN

In order to secure a monthly record of the number of cases of malaria in Herrin, the physicians were asked to record their cases on blanks furnished them for that purpose. The monthly summary of their reports is given in the following table.

NUMBER OF CASES OF MALARIA IN HERRIN, 1920

Physician	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Totals.
W. R. Gardiner	0	0	0	0	0	0	0	1	0	1
E. M. Sanders	0	0	0	0	1	0	0	0	1	2
G. C. Chamness	3	5	6	6	9	9	9	4	0	51
D. S. Boles*	4	3	4	13	12	10	12	0	0	58
Carl Baker	0	0	0		0	0	0	0	0	0
L. W. Brown and F. C. Murrah	0	0	0	0	20	27	25	24	18	114
J. S. Waldman	0	2	2	2	0	2	1	4	0	13
R. E. Ransmeyer	0	2	1	0	1	1	1	0	2	8
Totals.....	7	12	13	21	43	49	48	33	21	247

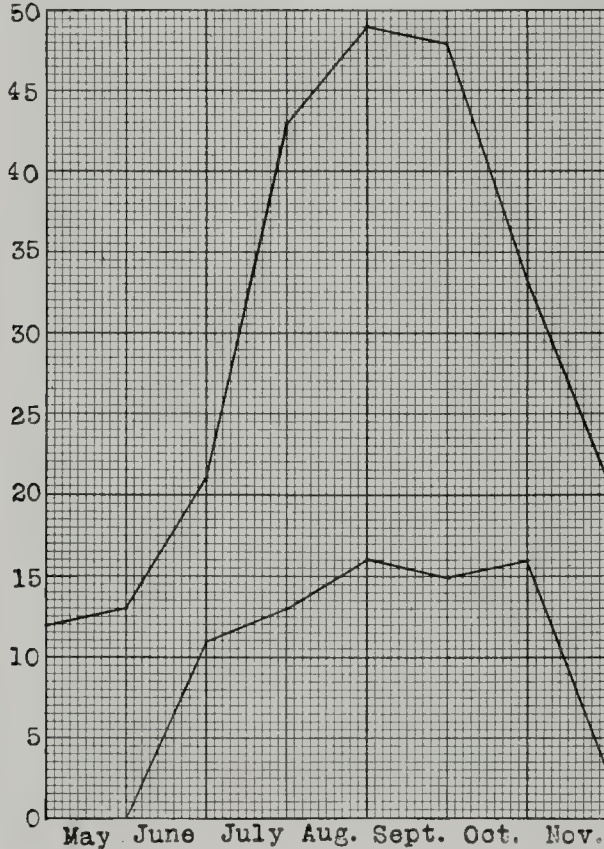
*Dr. Boles' practice was taken over on October 1, by Dr. R. L. Kane.

It should be said, in connection with these malaria records, that diagnosis was very often made by symptoms of disease and not by the blood test, a lack which may cause some inaccuracies in the foregoing records. However, even if a physician does not make blood tests, his records are probably as accurate in one month as in another.

RELATION BETWEEN MALARIA AND THE MALARIAL MOSQUITOES

Since malaria can be transmitted to man only through the bite of certain species of Anopheles, there should be some correspondence between the amount of malaria and the abundance of Anopheles in a given place. To bring out this relationship at Herrin, I have plotted the following curves, comparing the monthly totals of the number of cases of malaria reported by physicians with the monthly totals of numerical values taken from the Anopheline mosquito breeding-record. These curves clearly follow each other in a general way; and the fact that there were cases of malaria reported before any Anopheles were found is prob-

ably due to hold-over cases, which reappeared as the weather warmed up in spring.



Number of cases of malaria (upper line), and abundance of Anopheline mosquitoes (lower line).

SPECIES OF MOSQUITOES AT HERRIN, 1920

The following table gives the species of mosquitoes reared from collections at Herrin, the months when collected, and the numbers of the breeding places in which they were found. For example, the first species listed (*Anopheles guttulatus*) was bred from larvae or pupae collected in August from breeding places Nos. 4 and 5, in September from Nos. 4 and 7, and in October from Nos. 5 and 6.

Of these eleven species, three are worthy of special notice, namely, *Anopheles crucians*, *Aedes sollicitans*, and *Culex degustator*. The first two are distinctly salt-marsh species, very rarely found more than fifty miles from salt water. Dr. Harrison G. Dyar, who confirmed the determinations of these species, expressed great surprise that they were found

so far inland, and suggested that there might be some salt deposits or salt springs in the vicinity, creating conditions approximating those of the seacoast. This is entirely possible, as those familiar with the history and geology of southern Illinois are well aware. There is certainly much salt under the surface, from Murphysboro east to the Ohio River, as witnessed by the salt springs, salt wells, and old salt works which were at one time of commercial importance, and it is possible that the waste water from the mines is a factor in the production of salt-marsh conditions at Herrin. The last of the three species has been taken before in the Mississippi Valley. It is a new species, and is to be called *Culex degustator* by Dr. Dyar.

SPECIES OF MOSQUITOES REARED FROM IMMATURE STAGES,* HERRIN, 1920

Species.	Breeding place and month collected,†						
	Apr.	May	June	July	Aug.	Sept.	Oct.
<i>Anopheles guttulatus</i> Harris					4, 5	4, 7	5, 6
<i>A. punctipennis</i> (Say) Say			4, 7	4, 7	.....	5, 8	
<i>A. crucians</i> Wied.						3	
<i>Culiseta inornata</i> (Williston) Dyar							6
<i>Culex apicalis</i> Adams (<i>saxatilis</i> Gross.)							7
<i>Culex territans</i> Walker (<i>restuans</i> Theob.)		5	.....	5	1, 5		
<i>C. pipiens</i> Linn.			1	.....	8	5, 8	1, 6
<i>C. salinarius</i> Coquillett						1, 3, 5	1, 7, 8
<i>C. degustator</i> Dyar, sp. n.			6	4	3, 4, 7		
<i>Aedes canadensis</i> (Theob.), D. & K.	4						
<i>A. sollicitans</i> (Walker) D. & K.		4, 5					

* The last species listed in this table was not reared, but taken as an adult. All the others were reared; not taken in the adult stage.

† Breeding places numbered 1 to 8 are described below, and 1 to 7 are indicated on the map, p. 24.

Description of Breeding Places referred to in the Table by Number

1. Open drain, with small feeders, running through town of Herrin.
2. Sink-holes, or hollows, filled with water.
3. Mine pond (Sunnyside Mine) from which water for boilers and washers is drawn.
4. Series of woodland pools in low-lying lands.
5. Large woods-swamp.
6. Mine ponds (C. W. & F. Mining Co. Mine A).
7. Mine ponds (Big Muddy Coal Co. Mine 7).
8. Domestic breeding-places in Herrin: tin cans, wells, cisterns, etc.

Further data were obtained this season on the relative abundance of *Anopheles guttulatus* and *A. punctipennis*. The fact was brought out in the survey work at Carbondale, reported by the author in the operations of 1918 and 1919, that the former species, considered the more effective carrier of malaria, was outnumbered 12 to 1 by the latter; but at Herrin during the season of 1920, there were exactly as many *guttulatus* reared from the monthly collections as *punctipennis*.

CONCLUSION

Control measures were discussed in full in the report of the operations of 1918 and 1919, mentioned in the introduction to this article. At Herrin, owing to the necessity of maintaining ponds, drainage—one of the best methods of control—can not be employed. It is quite likely that cleaning the edges, stocking the pond with fish (especially with top-minnow), or applying oil in some way, will be found to be the most practical methods.

STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION
DIVISION OF THE
NATURAL HISTORY SURVEY
STEPHEN A. FORBES, Chief

Vol. XIV.

BULLETIN

Article IV.

Changes in the Bottom and Shore Fauna of
the Middle Illinois River and its Con-
necting Lakes since 1913--1915 as a
Result of the Increase, South-
ward, of Sewage Pollution

BY

ROBERT E. RICHARDSON



PRINTED BY AUTHORITY OF THE STATE OF ILLINOIS

URBANA, ILLINOIS

December, 1921

STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION
W. H. H. MILLER, *Director*

BOARD OF
NATURAL RESOURCES AND CONSERVATION
W. H. H. MILLER, *Chairman*

WILLIAM TRELEASE, *Biology*
JOHN M. COULTER, *Forestry*
ROLLIN D. SALISBURY, *Geology*
WILLIAM A. NOYES, *Chemistry*

JOHN W. ALVORD, *Engineering*
KENDRIC C. BABCOCK, *Representing the*
President of the University of Illi-
nois

THE NATURAL HISTORY SURVEY DIVISION
STEPHEN A. FORBES, *Chief*



SCHNEPP & BARNES, PRINTERS
SPRINGFIELD, ILL.
1921

55188—1200

ARTICLE IV.—*Changes in the Bottom and Shore Fauna of the Middle Illinois River and its Connecting Lakes since 1913—1915 as a Result of the Increase, Southward, of Sewage Pollution.* BY ROBERT E. RICHARDSON.

The following short account of the principal changes that have occurred both in the composition and abundance of the small bottom-invertebrate fauna of the Illinois River system between Chillicothe and Brown-ing since 1913—1915—these points being respectively 146.5 and 229.5 miles below the mouth of the Chicago River—is based on hauls made in July, August, and September, 1920, with the Petersen quantitative bot-tom-sampler at seventy-one stations in the river and Peoria Lake between Chillicothe and the head of Grand Island, and at twenty-five stations in five of the more important bottom-land lakes in the neighborhood of Havana. While the composition of the small bottom-fauna was appar-ently normal as far north as Chillicothe in 1915,* the 1920 data herein pre-sented disclose conspicuous changes since that time both throughout the northernmost and southernmost portions of the section of river system studied, these including sweeping reductions in numbers and poundage of the still surviving groups of small bottom-animals, total obliteration of numerous families and species, and, in the range covered above Havana, the intrusion in large numbers of new pollutorial or tolerant forms. If, as is approximately correct, we assume that Chillicothe marked about the upper limit of wholesome conditions in the bottom muds in 1915, then the added river mileage that is shown to have been more or less seriously damaged since that time figures out at not less than eighty, and represents an average southward encroachment of pollution amounting to fully six-teen miles per year for each year of the five.

Valuations of the small bottom-animals have been made in the same manner as for the 1915 material reported upon in the paper just cited. Valuable assistance in working up the Chironomidae of the collections of this year, as well as in the elucidation of older data for comparison, has been given by Dr. C. P. Alexander and Mr. J. R. Malloch.

* The Small Bottom and Shore Fauna of the Middle and Lower Illinois River and its Connecting Lakes, Chillicothe to Grafton: its valuation; its Sources of Food Supply; and its Relation to the Fishery. By R. E. Richardson. Bul. Nat. Hist. Survey, Vol. 13, Art. XVI. 1921.

SYNOPTIC LIST OF DREDGING STATIONS, ILLINOIS RIVER AND
CONNECTING LAKES, JULY—SEPTEMBER, 1920

1. ILLINOIS RIVER AND PEORIA LAKE, CHILLICOTHE TO WESLEY
MILE 146.5—MILE 167.8 BELOW LAKE MICHIGAN

	Channel	4—7 feet.	1—3 feet.	Total
Upper lake, Chillicothe to Spring Bay, Mile 146.5—153.2	3	4	1	8
Middle lake, Mossville to Al Fresco Park, Mile 154.9—159.3	3	4	1	8
Peoria Narrows, Mile 161.0	1	1	0	2
Lower lake, Straw-board Mill to Liberty St., Mile 161.7—164.2	8	3	4	15
Peoria and Pekin Union Railway Bridge, Mile 166.4	1	1	0	2
Total	16	13	6	35

2. ILLINOIS RIVER, LIVERPOOL TO 1.5 MILES BELOW HEAD OF GRAND ISLAND
MILE 199.0—MILE 215 BELOW LAKE MICHIGAN

	Channel	4—7 feet.	1—3 feet.	Total
Liverpool to Havana, Mile 199.0—207.0	7	7	0	14
2 miles below Havana to 1.5 miles below head of Grand Island, Mile 209.0—215.0	11	8	3	22
Total	18	15	3	36

3. ILLINOIS VALLEY LAKES, LIVERPOOL TO 3.5 MILES ABOVE BROWNING
MILE 199.0—MILE 226 BELOW LAKE MICHIGAN

Lakes north of Havana, Mile 199.0—207.0	All mud bottom, Depths, 2—6 ft.	
Liverpool Lake	5	15
Dogfish Lake	3	
Thompson Lake	3	
Quiver Lake	4*	
Lakes south of Havana, Mile 224.0—226.0		
Stewart Lake	5	

* In Quiver Lake five additional collections were made in the deep channel cut by the wash from Quiver Creek and in the sandy-muddy zone near the east beach.

The Illinois River and Peoria Lake, Chillicothe to Wesley
(Mile 146.5—167.8 below Lake Michigan)

At all of the thirty-five lake and river stations between Chillicothe and Wesley where bottom dredgings were made in 1920, there was evidence in some form or other of deteriorating change since 1915. The various tests and observations made both in 1920 and five to seven years earlier had regard chiefly to the physical condition, appearance, and odors of the muds; the composition and abundance of the small bottom- and shore-fauna; and the kinds, amount, and distribution of the coarse aquatic vegetation. While sharply drawn comparisons are not easy in the first group of items, bubbling and more or less foul odors having been noted at some stations between Peoria and Chillicothe in 1915, in the second itemization we have to do with the disappearance since that year of whole families and numerous genera and species of small bottom-animals, as well as with the entrance in their place, in several instances, of new pollutional forms; and in the last, with the practically complete disappearance of a rich aquatic vegetation which formerly covered several square miles of shallow-lake territory at low water, along with the similarly complete extingishment of a previously very rich shore- and weed-fauna.

The muds, taken at the eight stations in the "upper lake," between Chillicothe and Spring Bay, were all strong in odor, and bubbling was abundant, when the mud was stirred, in all depth-zones. Both in the channel at Rome and Spring Bay and in the open lake opposite Rome a peculiarly spongy and foul-smelling mud was lifted by the dredge. These samples showed a texture not unlike freshly risen bread, and gave out a distinct blubbering sound on being pressed with the hand as they lay

in the tray. Some improvement in odor and less bubbling was noted in samples taken well toward the east edge of the upper lake.

In the middle lake, opposite Mossville, the mud from the channel was spongy with gas, and in the channel of this lake as far south as Al Fresco Park, a mile and a half above Peoria Narrows, odors were foul and strong. Considerably less bubbling and milder odors were noted at the shallower-water stations in this section of Peoria Lake.

In the lower lake, opposite and below the principal sewers of the business and residence districts of the city of Peoria, all dredgings were made in the center or to the eastward of the steamboat channel and were for the most part out of the way of the worst of the local pollution. At our stations in the lake, neither in the main channel nor in the shallower water eastward were odors so bad as at upper-lake stations, although bubbling was abundant in whatever depth the dredge was let down. At all stations, both in this and in the upper and middle lake, it was noted that all dead shells of snails were badly blackened or otherwise discolored.

The principal changes in the bottom fauna in this 18-mile section since 1915 may be summarized under three heads: (1) disappearance of most species and genera and of several families of small Mollusca, along with important average decrease in numbers of the more tolerant forms still surviving; (2) enormous increase in larval midges (Chironomidae), with invasion of several more or less distinctly pollutional species, and similar or even greater increase in sludge-worms (Tubificidae); and (3) disappearance throughout Peoria Lake, except immediately along shore or in the short, half-mile, stretch of swifter water in Peoria Narrows, of all "other insects"* (Ephemeridae, Odonata, Phryganeidae, Corixidae, etc.), as well as of planarians and leeches, Amphipoda, Isopoda, sponges, and Bryozoa.

Although in 1913—1915 at least fifteen or sixteen species of snails, representing no less than eight families, were readily taken in the lake and river channel between Chillicothe and Peoria, but four species, representing three families, were found in the same range in July and August, 1920. The three principal surviving kinds (*Campeloma subsolidum*, Pleurocera species, and *Musculium transversum*) were those found by us farthest north—and hence most tolerant of foul water and bottom—in the upper Illinois in 1912, the first-named species occurring as far north that year as Starved Rock, and the last as far north as Marseilles. Two of the formerly abundant species of Viviparidae (*Vivipara contectoides* and *Lioplax subcarinata*), two species of Valvata, two Amnicolas, three or four species of Physidae and Planorbinae, a species of Ancyclus, and at least three species of Sphaeriidae seem to have disappeared altogether from the muds between 1915 and 1920.

* Understood in text and tables following to mean other insects than Chironomidae.

SNAIL FAUNA* OF BOTTOM MUDS, CHILlicothe TO FOOT OF PEORIA LAKE, 1913—1915 TO 1920

I. *Species surviving in 1920, and their distribution.*

1. Viviparidae.. 1. *Campeloma subsolidum*.....East side lake, opposite Rome; channel and 4—7 feet, lower lake.
2. Pleuroceridae 2. *Pleurocera* sp.....Channel of lower lake only.
3. Sphaeriidae.. 3. *Musculium transversum*.....Both zones, upper lake; shallower zone, middle lake; channel, lower lake.
- “ 4. *Sphaerium stamineum*.....Channel, lower lake, one occurrence.

II. *Species common or abundant in 1913—1915, but not found in 1920, and distribution in former period.*

1. Viviparidae.. 1. *Vivipara subpurpurea*.....Lower lake only.
- “ 2. *V. contectoides*.....Abundant in both zones, Chillicothe to Peoria.
- “ 3. *Lioplax subcarinata*.....Common to abundant, principally in channel.
2. Amnicolidae 4. *Amnicola emarginata*.....Common locally.
- “ 5. *Somatogyrus* sp.....Upper lake only.
3. Valvatidae... 6. *Valvata bicarinata*.....Common outside of channel.
- “ 7. *V. tricarinata*.....Common outside of channel.
4. Physidae.... 8—9. *Physa* spp.....Common in shallower zones.
5. Planorbinae 10—11. *Planorbis* spp.....Common in shallower zones.
6. Sphaeriidae 12. *Sphaerium striatinum*.....Lower lake only.
- “ 13. *Musculium jayanum*.....Scattered occurrences.
- “ 14. *Pisidium* sp.....Common.
7. Ancyliidae... 15. *Ancylus* sp.....Common on shells of Unionidae.

* Nomenclature that of F. C. Baker, in "A Catalogue of the Mollusca of Illinois," Bul. Ill. State Lab. Nat. Hist., Vol. 7, Art. VII, Sept., 1906.

Even the surviving snails showed in 1920 great reduction in average numbers and weight since 1915 in nearly all portions of the area studied. The extent to which they had shrunk in the different depth-zones of the upper, middle, and lower lake is shown in the comparative valuation tables appended, and it will be sufficient here to note that whereas in 1915 the weight of the combined Gastropoda and Sphaeriidae in Peoria Lake collections made up from over 85 to over 99 per cent. of the total edible matter in the average haul, the snails in 1920, except in the short swift stretch through Peoria Narrows and in a few collections in the channel of the lower lake, weighed on the average less or only a little more than did the sludge-worms or midge larvae, and made up, in fact, only from 2 to 15 per cent. of the average catch under the new dispensation.

The Viviparidae and Pleuroceridae in 1920 were found only in the channel and 4—7-foot zone of the lower lake, opposite Peoria, and in the 1—3-foot zone, on the east side in the Rome—Mossville section. The single surviving species of Sphaeriidae (*Musculium transversum*) showed a visibly wider distribution than the large Gastropoda, and it was somewhat of a surprise to us to take the largest hauls of this stoutly tolerant little shell among the sludge-worms and larval midges of the filthy channel-bottom between Chillicothe and the foot of the upper lake.

SNAIL FAUNA OF BOTTOM MUDS, CHILLICOTHE TO FOOT OF PEORIA LAKE,
1915 AND 1920

1. Average number per square yard, main groups

		Channel		4-7-ft. zone		1-3-ft. zone	
		1915	1920	1915	1920	1915	1920
Viviparidae and Pleuroceridae	Upper lake	111	0	32	0	10	24
	Middle lake	19	0	28	0	7	0
	Lower lake	134	63	153	8	50	0
Sphaeriidae	Upper lake	152	112	204	24	12	24
	Middle lake	91	0	116	3	277	12
	Lower lake	5	6	97	0	30	0
Amnicolidae, Valvatidae, etc.	Upper lake	6	0	3	0	32	0
	Lower lake	0	0	12	0	12	0
	Middle lake	0	0	70	0	40	0

2. *Average weight, main groups, pounds per acre,
shells deducted*

		Channel		4-7-ft. zone		1-3-ft. zone	
		1915	1920	1915	1920	1915	1920
Viviparidae and Pleuroceridae	Upper lake	317	0	87	0	50	72
	Middle lake	26	0	57	0	18	0
	Lower lake	391	110	446	24	174	0
Sphaeriidae	Upper lake	76	56	88	12	6	12
	Middle lake	43	0	54	1	66	6
	Lower lake	3	3	28	0	1	0
Amnicolidae, Valvatidae, etc.	Upper lake	0.8	0	0.1	0	8.5	0
	Middle lake	0	0	1.7	0	0.6	0
	Lower lake	0	0	27.4	0	8.6	0

3. *Average weight of total snails
and per cent. decrease, 1915 to 1920*

		1915	1920	Per cent. decrease
Upper lake	Channel	394	56	85.7
	4-7 ft.	175	12	93.1
	1-3 ft.	64	84	31.2*
Middle lake	Channel	69	0	100.0
	4-7 ft.	113	1	99.1
	1-3 ft.	86	6	93.0
Lower lake	Channel	394	113	71.3
	4-7 ft.	501	24	95.2
	1-3 ft.	184	0	100.0

* Increase.

4. Percentage, by weight, of average total hauls
contributed by snails

	Channel		4-7-ft. zone		1-3-ft. zone	
	1915	1920	1915	1920	1915	1920
Upper lake	99.4	13.6	95.1	6.6	85.3	91.1
Middle lake	93.2	0	91.1	1.8	89.5	12.5
Lower lake	98.8	55.1	98.8	15.3	95.3	0

The changes in composition and abundance of the chironomid population of the bottom muds in this section of the river since 1915 are perhaps even more interesting and significant than those of the small Mollusca, including, as they do, the appearance of several new and more or less pollutional species, the disappearance of a number of formerly common or abundant cleaner-water forms, and an almost sixty-fold multiplication in weight of the average chironomid contribution to hauls since 1915.

Unusually tolerant or pollutional species that have come into Peoria Lake since 1915 seem to be several in number, and include *Chironomus plumosus* Linn., *C. matus* Joh., *C. frequens* Joh., and a variety of the first-named species. *Chironomus plumosus* L. has before been recorded by writers in Europe as a species common in foul muds. It was taken by us in 1920 in large numbers all the way from Chillicothe to the foot of Peoria Lake, both in the channel and in the shallower zones, and also occurred in moderate numbers in the gassy river-muds eight miles above Havana. It was not found by Malloch in 1912 or 1913 collections from either above or below Peoria, but appears to have been present in the badly fouled bed of the Des Plaines River at Lockport in the autumn of 1911, as indicated by a provisional determination by Mr. Chas. A. Hart. *Chironomus matus* Joh. and *C. frequens* Joh. are here listed as species capable of maintaining themselves in polluted muds because of their occurrence in 1920 in abundance in the Illinois River opposite Peoria, and because of the absence of definite records of them from clean muds elsewhere—either in the Illinois River or other waters.

Three more or less tolerant or pollutional species, *Tanytus dyari* Coq., *Chironomus decorus* Joh., and *C. crassicaudatus* Mall., may be listed as hold-overs from 1913—1915, when, as in 1920, they were common in collections from some stations opposite or above Peoria. We note that *C. decorus* was the commonest species of this family found by Weston and Turner in the contaminated bottom of the Coweaset River in 1916, just below the drains of the city of Brockton, Mass. *Tanytus dyari* Coq. was found by Malloch some years ago to frequent a badly polluted local

ditch in Illinois, and was taken by us in 1912 in the worst fouled portions of the Illinois River between Morris and Marseilles, though not northward of those places. None of these three species was found by us either in 1920 or in 1913 south of Peoria; and the last one named, nowhere at all except at Peoria.

The list of larval midge-species that have dropped out of this section of the Illinois River since 1915 includes at least four, of which but one, *Chironomus tentans* F., is known definitely to do badly in the presence of pollution and to have been common in this section during or before 1915. This species was common to abundant in 1913—1915 both in the river and in the lakes all the way from Peoria Lake to Havana, but has now apparently disappeared altogether from the lakes and from the greater portion of its old river-range. Species of apparently rather indifferent habit as indicated by their distribution in this section and above and below six or seven years ago, but that failed to appear in Peoria Lake collections in 1920, are two in number—*C. lobiferus* Say and *C. viridicollis* v. d. W.

MIDGE LARVAE (CHIRONOMIDAE*) OF BOTTOM MUDS OF ILLINOIS RIVER AND PEORIA LAKE.

CHILICOTHE TO WESLEY, 1913—1914 TO 1920—JULY—OCTOBER

1. *Pollutinal or tolerant species that have come in since 1913—14.*

Chironomus plumosus L....Des Plaines River, Lockport, 1911, Hart...Common, 1920, Chillicothe to Peoria, and Havana to Liverpool.

C. plumosus L., var.....Common, 1920, lower Peoria Lake, but not south of Peoria.

C. matus Joh.....† Common, 1920, lower Peoria Lake, but not south of Peoria.

C. frequens Joh.....† Common, 1920, lower Peoria Lake, but not south of Peoria.

2. *Tolerant or indifferent species common both 1913—14 and 1920.*

Tanytopus dyari Coq.....Peoria, 1913; Morris to Marseilles, 1912...Common, Chillicothe to Peoria Narrows, 1920.

Chironomus decorus Joh....Common at Peoria and present at Havana, 1913

C. crassicaudatus Mall.....Adults taken by Hart at Peoria, 1914....Common in lower Peoria Lake, 1920.

3. *Tolerant or indifferent species that have dropped out since 1913—14.*

Chironomus lobiferus Say....Common, 1912—13, Havana to Peoria and north to Depue.

C. viridicollis v. d. W.....Common, 1912—13, Havana to Peoria and north to Marseilles.

4. *Cleaner-water species, or species of doubtful position, that have dropped out since 1913—14.*

Chironomus nigricans Joh...Peoria Narrows, 1913.

C. tentans F.....Common, Havana to Peoria, 1913- 15.

Cricotopus sp.....Peoria, 1913.

Orthocladus sp.....Peoria, 1913.

* It will be noted that this list and other lists of Chironomidae following are complete, either for 1950 or 1913—15, only so far as they concern more or less definitely determined species; several species of uncertain position, both periods, are omitted.

† Adults and pupal exuviae.

The vast increase in numbers and weight of midge larvae in the muds of Peoria Lake between 1915 and 1920, the comparison being of July—September collections for both periods, goes far in some portions of the range toward making up the losses in the small Mollusca. While the average number of young midges taken to the square yard between Chillicothe and the foot of the lake was less than 10 in the summer of 1915, in 1920 it had risen for the whole lake to 318; while in the channel and 4—7-ft. zone of the upper lake, between Chillicothe and Spring Bay, numbers per yard were 1216 and 554. Again, while in 1915 the greatest weight per acre figured for Chironomidae in a subdivision of Peoria Lake (the 4—7-ft. zone of the middle lake) was only 7 pounds, and the average for all zones and all subdivisions in 1915 was only 1.4 pounds, in 1920 the average weight had risen in the channel and 4—7-ft. zones of the upper lake to 182 and 128 pounds respectively, and for all subdivisions and all zones to 83.3 pounds, or 59.5 times the average valuation figure of 1915. When we compare the weight of the Chironomidae with the weight of the average total haul we find that the largest catches in Peoria Lake in 1915 ran less than 6 per cent. Chironomidae, most of the collections, in fact, running less than 3 per cent. In 1920, on the other hand, we find the Chironomidae making up from 21 to 42 per cent. of the average total weight of collections in the channel between Chillicothe and Peoria, and from 70 to 96 per cent. in the 1—3-ft. and 4—7-ft. zones.

MIDGE LARVAE (CHIRONOMIDAE) OF BOTTOM MUDS,
CHILLICOTHE TO FOOT OF PEORIA LAKE, 1915 AND 1920

1. Number and weight per unit of bottom area

		Channel		4—7-ft. zone		1—3-ft. zone	
		1915	1920	1915	1920	1915	1920
Average No. per sq. yard	Upper lake	2	1216	13	554	12	0
	Middle lake	10	36	21	201	5	84
	Lower lake	0	244	0	332	0	198
Average pounds per acre	Upper lake	0.2	182	4.2	128	2	0
	Middle lake	1.5	5	7	51	3	42
	Lower lake	0	86	0	132	0	24

Average weight per acre, all channel collections, 1920, 89.2 lbs.

“ “ “ “ all 4—7-ft.-zone collections, 1920, 101.0 lbs.

“ “ “ “ all 1—3-ft.-zone collections, 1920, 27.6 lbs.

Average weight per acre, all collections, all zones, 1920, 83.3 lbs.

Average weight per acre, all collections, all zones, 1915, 1.4 lbs.

2 *Percentage, by weight, of average total hauls
contributed by Chironomidae*

	Channel		4-7-ft. zone		1-3-ft. zone	
	1915	1920	1915	1920	1915	1920
Upper lake	0.08	44.2	2.2	71.1	2.6	0
Middle lake	2.0	20.8	5.7	96.2	3.4	87.5
Lower lake	0	41.9	0	84.7	0	82.7

Much as have the sludge-worms, the larvae of the midges have increased in the past five years in Peoria Lake from an average of half a pound per acre and a maximum of one pound—representing at the most less than 2 per cent. of the average total haul—to as much as 173 pounds per acre and 42 per cent. of the average haul in the river channel between Chillicothe and Spring Bay, and to a general average of 26.3 pounds per acre for all subdivisions and all zones collected from in the three lakes. The largest numbers reached—in the channel of the upper lake—amounted to 4960 per square yard, 4800 of these belonging apparently to a single species of *Tubifex*, and 160 to a species of an undetermined genus of *Tubificidae*. Both in the channel and in the shallower zones, sludge-worms became less abundant southward of the upper lake, though it is noted that in the channel of the lower lake the average number per square yard in 1920 (183) was more than sixteen times the average figure for the upper lake channel (11) in 1915 (table).

SLUDGE-WORMS (PRINCIPALLY *TUBIFICIDAE*),
CHILLICOTHE TO FOOT OF PEORIA LAKE, 1915 AND 1920
1. *Number and weight per unit of bottom area*

		Channel		4-7-ft. zone		1-3-ft. zone	
		1915	1920	1915	1920	1915	1920
Average No. per sq. yard	Upper lake	11	4960	26	1146	37	240
	Middle lake	0	540	0	36	0	12
	Lower lake	17	183	0	0	0	144
Average pounds per acre	Upper lake	0.3	173	1	40	1	8
	Middle lake	0	19	0	1	0	0.4
	Lower lake	0.6	6	0	0	0	5

Average weight per acre, all channel collections, 1920, 44.5 lbs.

“ “ “ “ all 4—7-ft.-zone collections, 1920, 14.0 lbs.

“ “ “ “ all 1—3-ft.-zone collections, 1920, 4.7 lbs.

“ “ “ “ all collections, 1920, all zones, 26.3 lbs.

“ “ “ “ “ “ 1915, “ “ 0.5 lbs.

2. Percentages, by weight, of average total hauls
contributed by sludge-worms

	Channel		4-7-ft. zone		1-3-ft. zone	
	1915	1920	1915	1920	1915	1920
Upper lake	0.07	42.0	0.4	22.0	1.7	8.7
Middle lake	0	79.0	0	2.0	0	trace
Lower lake	0.15	3.0	0	0	0	17.3

Out of a miscellaneous list of insects representing five or six families other than Chironomidae that were present or common in the bottom muds between Chillicothe and the foot of Peoria Lake in 1915, we found none at all surviving in the summer of 1920 at the thirty-one stations dredged in the sluggish waters of either the channel or shore zones of Peoria Lake proper or in the river at Chillicothe. At these same stations we failed also to find any isopods, the little amphipod *Hyaella*, any leeches or planarians, or any sponges or bryozoans. In the relatively much swifter water that continues for about a half mile through Peoria Narrows, however, and in the rapid portion of the river just below the lower outlet of the lake, large Viviparidae and Pleuroceridae were present in larger numbers than in the upper, middle, or lower lake, a bryozoan, *Fredricella* sp., was thriving on the shells of living snails, and the formerly common sand-case-building caddis larva (*Hydropsyche* sp.) was still present in considerable numbers. As the average valuation figures of this group of the bottom invertebrates ran only two to eight pounds per acre in Peoria Lake in 1915, it will be recognized that the decline is a small one compared with the losses since 1915 in Mollusca, and that it has been much more than made up in bulk and weight by the recent increases in the sludge-worms and the larvae of the midges.

OTHER INSECTS,* WORMS, CRUSTACEA, ETC. OF BOTTOM MUDS,

CHILLICOTHE TO FOOT OF PEORIA LAKE, 1915 AND 1920

NUMBER AND WEIGHT PER UNIT OF BOTTOM AREA

		Channel		4-7-ft. zone		1-3-ft. zone	
		1915	1920	1915	1920	1915	1920
Average No. per sq. yard	Upper lake	12	0	31	0	72	0
	Middle lake	23	0	12	0	42	0
	Lower lake	30	0	52	0	120	0
Average pounds per acre	Upper lake	2	0	4	0	8	0
	Middle lake	4	0	4	0	7	0
	Lower lake	5	0	6	0	7	0

* See foot-note p. 7.

The sum of the various changes that have taken place in the small bottom-fauna of Peoria Lake since 1915, as shown in the summary tables next following, have not apparently affected average total valuation figures in pounds per acre since 1915 nearly as much as they have changed the composition of the fauna. In the upper lake, in fact, it appears that the 1920 figures, for all zones—in consequence principally of the enormous increase of midge larvae and sludge-worms since 1915—indicate total stocks slightly heavier than five years before. In the middle and lower lakes, however, average figures for all zones seem to have been cut at least in two when not divided by three, and an estimate of an average reduction of around 50 per cent. in all zones of all three lakes combined would apparently be a fair approximation of the total change.

It is, we believe, the losses in the shore and weed fauna, rather than those in the bottom animals, that have bulked greatest in Peoria Lake in the past few years. The loss in this element of the small invertebrate fauna of the lake has without question been almost a total one since 1915. The luxuriant growths of coarse aquatic plants (*Potamogeton*, *Ceratophyllum*, *Scirpus*, *Vallisneria*, etc.) that covered several square miles of Peoria Lake at midsummer and autumn levels between 1910 and 1914, and their rich fauna of small invertebrates along with them have disappeared now altogether in the upper and middle lake except for an occasional scraggly clump at the very edge. In the lower lake, a thin patch of *Potamogeton* and *Ceratophyllum*, covering less than two acres, was still growing in the small springy slough on the east side, opposite the foot of Liberty St., in August, 1920—the sole more than negligible remnant of the several hundred acres of vegetation in this part of Peoria Lake at low water five to ten years ago.

ALL SMALL BOTTOM-ANIMALS, CHILLICOTHE TO WESLEY, 1915 AND 1920
AVERAGE VALUATIONS, POUNDS PER ACRE: SUMMARY

1. UPPER PEORIA LAKE, CHILLICOTHE TO SPRING BAY

	Channel		4-7-ft. zone		1-3-ft. zone	
	1915	1920	1915	1920	1915	1920
Viviparidae and Pleuroceridae	317	0	87.5	0	50	72
Sphaeriidae	76	56	87.9	.12	6.2	12
Amnicolidae, Valvatidae, etc.	0.8	0	0.1	0	8.5	0
Chironomidae	0.2	182	4.2	128.6	1.8	0
Oligochaeta	0.3	173	0.9	40	1.3	8
Other insects, worms, Crustacea, etc.	1.9	0	3.9	0	7.7	0
Grand total	396.2	411	184.5	180.6	75.5	92

2. MIDDLE PEORIA LAKE, MOSSVILLE TO AL FRESCO PARK

	Channel		4-7-ft. zone		1-3-ft. zone	
	1915	1920	1915	1920	1915	1920
Viviparidae and Pleuroceridae	26.1	0	57.1	0	18.5	0
Sphaeriidae	42.7	0	54.0	1.5	66.6	6
Amnicolidae, Valvatidae, etc.	0	0	1.7	0	0.6	0
Chironomidae	1.5	5	7.1	51	3.3	42
Oligochaeta	0	19	0	1.2	0	0.4
Other insects, worms, Crustacea, etc.	3.9	0	3.8	0	7.0	0
Grand total	74.2	24	123.7	53.7	96.0	48.4

3. LOWER PEORIA LAKE, STRAW-BOARD MILL TO LIBERTY STREET

Viviparidae and Pleuroceridae	391.6	110	446.3	24	174.0	0
Sphaeriidae	3.1	2.9	28.1	0	1.2	0
Amnicolidae, Valvatidae, etc.	0	0	27.4	0	8.6	0
Chironomidae	0	85.6	0	132.4	0	24.1
Oligochaeta	0.6	6.4	0	0	0	5
Other insects, worms, Crustacea, etc.	5.0	0	5.8	0	7.4	0
Grand total	400.3	204.9	507.6	156.4	191.2	29.1

4. PEORIA NARROWS, (STRONG CURRENT)

	Channel		4-7-ft. zone	
	1915	1920	1915	1920
Viviparidae and Pleuroceridae	46.3	227.	No coll.	174
Sphaeriidae	0.5	0.5	"	6
Amnicolidae, Valvatidae, etc.	0	0	"	0
Chironomidae	0	39.6	"	108
Oligochaeta	0	0	"	0
Other insects, worms, Crustacea, etc.	2.1	14.4	"	0
Grand total	48.9	281.5	"	288.0

5. PEORIA AND PEKIN UNION RAILWAY BRIDGE

(BELOW FOOT OF LAKE, IN STRONG CURRENT)

Viviparidae and Pleuroceridae	224.6	0	60	237
Sphaeriidae	8.3	0	136.7	0
Amnicolidae, Valvatidae, etc.	0	0	0	0
Chironomidae	7.0	0	0	3.6
Oligochaeta	0	0	0	1.2
Other insects, worms, Crustacea, etc.	13.9	0	9.6	24
Grand total	253.8	0	206.3	265.8

The Illinois River, Liverpool to Havana
(Mile 199.0—207.0 below Lake Michigan)

The changes between 1915 and 1920 in the appearance and odors of the muds in the eight-mile section of the Illinois next above Havana, whose upper and lower limits are respectively about 34 and 42 miles below the foot of Peoria Lake, and 199 and 207 miles below Lake Michigan, are, if anything, more striking than those that have occurred in the five years between Chillicothe and Peoria. In this part of the river in 1915

the mud had nearly uniformly a quite wholesome earthy odor in midsummer, and except locally along shore immediately below fish markets or large drains no more bubbling was noted when the bottom was disturbed than was normal at the same time at points fifty to a hundred miles farther south. In early July and early September, 1919, and in September, 1920, the muds taken both in and outside the deeper channel at Liverpool, at Hogfat Bend, three miles above Havana, and just above Havana were distinctly foul-smelling and hundreds of large gas bubbles rose to the surface each time the sampler hit bottom. In calm hot weather in late August, 1919, spontaneous bubbling was observed at Hogfat Bend and just above Liverpool; and at Liverpool in early September, 1920 the mud samples from the channel were of the same spongy texture previously noted in the samples from Rome and Chillicothe.

Both the shrunk volumes and altered composition of the collections of small bottom-animals taken at the fourteen stations worked in this section in 1920 add their clear testimony to the advance of pollution this far southward since 1915. While the average weight of the channel haul here was over 5,000 pounds per acre in 1915, in 1920 it was less than 250 pounds—a net loss of 95.3 per cent. In the 4—7-ft. zone for the same five-year period the average haul showed a shrinkage of 95.9 per cent., or from 2,122 pounds to only 87 pounds per acre. The change in the composition of the small bottom-fauna, in turn, includes the disappearance since 1915 of five out of seven families of snails; of more than half a dozen species of bottom-dwelling larval midges; and of twelve out of thirteen or fourteen families of “other insects,” worms, small Crustacea, and other small bottom-invertebrates.

By far the greatest destruction, as measured by bulk and weight as well as in numbers, appears to have been accomplished among the snails in the five-year period, the percentage declines in average snail-poundage in the channel and in the 4—7-ft. zone since 1915 (98.7 and 98.0 per cent.) being greater than the percentage decreases in poundage of total hauls (95.3 and 95.9 per cent.), and much greater than the percentage declines in snail yields in some important sections of river between Chillicothe and Peoria. While in Peoria Lake, as already pointed out, the decrease in snails in the five-year period was largely or altogether compensated by increase in the weight of the midge larvae and sludge-worms (principally the former), it is clear that under the circumstance in this section of a decline in snails from several thousand pounds to less than a hundred pounds per acre, an increase in Chironomidae from a trace to as much as 150 pounds per acre could go but a little way toward making up the snail deficiency. The following tabulation of changes in the snail fauna is substantially the same as the one previously given for the Peoria—Chillicothe section, showing the same three species—one each of Viviparidae, Pleuroceridae, and Sphaeriidae—still surviving, and principally the same list of about seventeen species that disappeared from the section in the five-year period under discussion.

SNAIL FAUNA OF BOTTOM MUDS OF ILLINOIS RIVER, LIVERPOOL TO HAVANA, 1913—1915 TO 1920

I. *Species surviving in 1920, and their distribution.*

1. Viviparidae	1. <i>Campeloma subsolidum</i>	Channel and 4—7-foot zone.
2. Pleuroceridae	2. <i>Pleurocera</i> sp.	" " "
3. Sphaeriidae	3. <i>Musculium transversum</i>	" " "

II. *Species present in 1913 to 1915 but not found in 1920, and distribution in former period.*

1. Viviparidae	1. <i>Lioplax subcarinata</i>	Abundant in channel, common in shallower zones.
"	2. <i>Vivipara confectoides</i>	Common to abundant, all zones.
"	3. <i>V. subpurpurea</i>	Present in channel.
2. Pleuroceridae	4. <i>Goniobasis</i> sp.	Present, 4—7 feet, off Cook's Island.
3. Amnicolidae	5. <i>Amnicola emarginata</i>	Common locally, various depths.
"	6. <i>Somatogyrus</i> sp.	Present, 4—7 feet, below Quiver Chute.
4. Valvatidae	7. <i>Valvata bicarinata</i>	Present within 7-foot line.
"	8. <i>V. tricarinata</i>	" " "
5. Planorbinae	9. <i>Planorbis trivolvris</i>	Common within 7-foot line.
"	10. <i>P. parvus</i>	" " "
6. Physidae	11—12. <i>Physa</i> spp.	" " "
7. Sphaeriidae	13. <i>Sphaerium stamineum</i>	Rare; in 4—7-foot zone only.
"	14. <i>S. striatinum</i>	Present in two or three collections, 4—7 feet.
"	15. <i>S. simile</i>	Rare; in channel.
"	16. <i>Musculium jayanum</i>	Scattered occurrences, never common.
8. Ancyliidae	17. <i>Ancylus</i> sp.	Common on shells of Unionidae in channel.

In the history of the Chironomidae of the river muds since 1915 in this district, after the disappearance of half a dozen of the old list of more sensitive species, perhaps the most important single circumstance is the appearance here in 1920 of the pollutional *Chironomus plumosus* Linn., which also invaded the Chillicothe—Peoria section for the first time in the five-year interval ending in 1920. This species was, in fact, quite common in September last year in the foul spongy mud taken at Liverpool, both in the channel and outside of it as far as the four-foot line, but was much rarer in the bottom samples at Hogfat Bend and just above Havana, its average for all the stations in the section being thus brought down to 20 per square yard.

The three other commonest species of midges represented in this section of the river in 1920 included two species of wide range or presumably tolerant habit, *Chironomus lobiferus* Say and a form near *C. decorus* Joh., and one hold-over species of more particular habit, *C. tentans* Fabr. *C. lobiferus* was recorded from Havana in 1913—1914 by Malloch, but was less common then than in 1920, when it averaged as high as 100 per square yard in channel collections. The *decorus*-like form had not been previously taken. *Chironomus tentans* F., which seems to have disappeared completely from its old range at and above Peoria since 1913—1914, as also from the lakes between Liverpool and Havana, was still holding its own in good numbers in 1920 at the lower (but not the upper) river-channel stations in the section.

MIDGE LARVAE (CHIRONOMIDAE) OF BOTTOM MUDS OF ILLINOIS RIVER, LIVERPOOL TO HAVANA, 1913—1914 TO 1920—JULY—OCTOBER

1. *Pollutional species that has come in since 1913—14.*

Chironomus plumosus L. Common at Liverpool in 1920.

2. *Tolerant or indifferent species that has come in since 1913—14.*

Chironomus sp., near *decorus* Joh., No. 1. Abundant, Liverpool to Havana, 1920.

3. *Tolerant or indifferent species found both 1913—14 and 1920.*

Chironomus lobiferus Say. Present, 1913—14. Common in channel only in 1920.

4. *Tolerant or indifferent species that have dropped out since 1913—14.*

Chironomus viridicollis v. d. W. Common, 1913—14.

C. decorus Joh. A few, 1913—14.

5. *Cleaner-water species that have dropped out since 1913—14.*

Tanytus monilis L. Common, 1913—14.

T. illinoensis Mall. Present, 1913—14.

Chironomus ferrugineovittatus Zett. Present, 1913—14.

C. modestus Say. Present, 1913—14.

Cricotopus trifasciatus Panz. Common, 1913—14.

Palpomyia longipennis Lw. Common, 1913—14.

6. *Cleaner-water species still surviving in 1920.*

Chironomus tentans F. Present in 1913—14, but less common in the river than in the connecting lakes. Commoner in the river in 1920 than in 1913—14, but apparently exterminated in the connecting lakes.

The extent of the increase in bulk and weight of Chironomidae in collections since 1915 (from a negligible quantity to 164 pounds per acre in the channel and from a similar figure to 45 pounds in the 4—7-ft. zone) is greater even than the increase shown by either the channel or all-zone figures for the Chillicothe—Peoria district. The percentage, by weight, contributed by Chironomidae to average total hauls in this district while standing practically at zero in 1915, reached 68.3 per cent. in the channel and 51.7 per cent. in the 4—7-ft. zone in 1920, these ratios comparing with 99.5 per cent. and 98.7 per cent. for snails and less than 2 per cent. for all other small bottom-animals during the period covered by the earlier valuations (table, p. 53.)

Sludge-worms, which showed a perpendicular rise from none at all in this section of river in 1915, were still far under the numbers and weight valuations recently reached in Peoria Lake, the average number per square yard at channel stations, where the largest quantities were taken, being less than 100, and the average valuation not over three pounds per acre. These figures compare with over 170 pounds per acre in the channel of upper Peoria Lake in 1920 and with over 26 pounds per acre as the all-zone average of the Illinois River and its wide waters between Chillicothe and south Peoria. The small oligochaetes taken between Liverpool and Havana in September, 1920, apparently belonged without exception to the Tubificidae, the commonest form being an undetermined species of the genus *Tubifex*.

As in the Chillicothe—Peoria reach, the miscellaneous minor groups of small bottom-animals all appeared in 1920 collections in this section in greatly reduced numbers and variety when they appeared at all. Insect families other than Chironomidae that were common in 1913—1915, but that seem to have disappeared altogether outside the 3- or 4-foot line since the latter year, include Corixidae, two species; Phryganeidae, species of *Hydropsyche* and other genera; Ephemeridae, species of *Hexagenia*, *Heptagenia*, and *Caenis*; Gomphidae, *Libellulidae*, and other families of Odonata; and Parnidae, as represented by adult beetles of the genus *Stenelmis*. Other small bottom-animals that have dropped out of the channel and 4—7-foot zone are the little amphipod *Hyalella knickerbockeri*, *Asellus aquaticus*, planarians of several kinds, as well as several kinds each of leeches, fresh-water sponges, and Bryozoa. The average weight-valuation of this group in 1920, 6 pounds per acre in the channel and one pound per acre in the 4—7-ft. zone, stands for comparison with 24 and 26 pounds in 1915, with the 1920 poundages largely made up of a single species of leech.

ALL SMALL BOTTOM-ANIMALS, ILLINOIS RIVER, LIVERPOOL TO
HAVANA, 1915 AND 1920

1. Average numbers per square yard

	Channel		4-7-ft. zone	
	1915	1920	1915	1920
Viviparidae and Pleuroceridae	1294	25	121	15
Sphaeriidae	0	34	3557	58
Amnicolidae, Valvatidae, etc.	2	0	0.4	0
Chironomidae	0	950	0	225
Oligochaeta	0	89	0	4
Other insects, worms, Crustacea, etc.	172	36	172	7
Grand total	1468	1134	3850	309

2. Average pounds per acre,
and per cent. decrease in five years

	Channel		4-7-ft. zone		Per cent. decrease, 1915-1920	
	1915	1920	1915	1920	Channel	4-7-ft.
Viviparidae and Pleuroceridae	5156	50	319	26	99.2	91.8
Sphaeriidae	0	17	1777	15		99.1
Amnicolidae, Val- vatidae, etc.	0.1	0	0.2	0		
Total Mollusca	5156	67	2096	41	98.7	98.0
Chironomidae	0	164	0	45		
Oligochaeta	0	3	0	0.1		
Other insects, worms, Crustacea, etc.	24	6	26	1	75.0	96.1
Grand total	5180	240	2122	87	95.3	95.9
Per cent. snails	99.5	27.9	98.7	47.1		
Per cent Chiro- nomidae.	0	68.3	0	51.7		

The Illinois River from 2 miles below Havana to 1.5 miles below the Head of Grand Island

(Mile 209.0—215.0 below Lake Michigan)

Neither in July—October, 1913—1915 nor at the same season in 1920 were foul odors or abnormal bubbling noted at the muddier collecting stations in this somewhat swifter and harder-bottomed section of river than the two previously described. The conspicuous change in the physical appearance and odor of the bottom sediments that occurs in less than three miles below the wagon bridge at Havana is no doubt influenced by several factors, including as the principal ones the effect of the high Spoon River bar in favoring sedimentation in the widened river immediately north of Havana, and the lesser rate of settling and greater mobility of bottom sediments in the stretch of faster channel that begins just below it.

The improvement in the condition of the stream bottom as we proceed southward of Havana is only a little less strikingly shown in the composition of the small bottom-fauna—if we except the Mollusca—than in the physical condition of the bottom deposits. Here in 1920, for the first time below Chillicothe, we found thriving the nymphs of the common willow-fly of the middle and lower Illinois, *Hexagenia bilineata*; something like normal numbers of the common sand-caddis, *Hydropsyche* sp., as well as immature Gomphidae and other Odonata; and among non-insect bottom-animals, about the usual variety of Bryozoa, leeches, and planarians. Even on the molluscan side we did not find serious decrease in total-weight valuations over 1915, either in the channel or in the 1—3-ft. zone. But there was a decline of 95 per cent. in snail poundage compared with five years before, indicated for the 4—7-ft. zone, and the full list of snails for the section showed the disappearance since 1915 of not less than eight species, representing five families. The only species surviving were, in fact, the same three—one each of Viviparidae, Pleuroceridae, and Sphaeriidae—which have pulled through in the Chillicothe—Peoria and Liverpool—Havana sections. The disappearance of these snails from the river below Havana is not, however, to be compared in seriousness with the visitations of mortality above Havana, both for the reason that neither in the channel or the shallower zones were average snail-yields here anything like as high some years ago as above Havana, and because the remaining species have apparently quite or more than held their own in at least a part of the range since the disappearance of the more sensitive forms.

SNAIL FAUNA OF BOTTOM MUDS OF THE ILLINOIS RIVER, BELOW HAVANA,* 1913-1915 TO 1920

I. *Species surviving in 1920, and their distribution.*

1. Viviparidae	1. <i>Campeloma subsolidum</i>	Small numbers, both channel and shores, where there is mud.
2. Pleuroceridae	2. <i>Pleurocera</i> sp.	"
3. Sphaeriidae	3. <i>Musculium transversum</i>	"

II. *Species present in 1913-15 but not found in 1920, and distribution in former period.*

1. Viviparidae	1. <i>Lioplax subcarinata</i>	Scattered occurrences.
"	2. <i>Vivipara contectoides</i>	Common locally.
"	3. <i>V. subpurpurea</i>	Scattered occurrences.
2. Pleuroceridae	4. <i>Goniobasis</i> sp.	Rare.
3. Amnicolidae	5. <i>Amnicola emarginata</i>	Small numbers locally.
"	6. <i>Amnicola</i> sp.	Common locally in shallower zones.
4. Sphaeriidae	7. <i>Sphaerium stamineum</i>	Rare.
5. Ancyliidae	8. <i>Ancylus</i> sp.	Not uncommon on live or dead shells.

* To 1.5 miles below head of Grand Island, 1920; to head of Grand Island, 1915.

Further evidence of a mixed status or condition of the bottom fauna in this portion of the river is furnished in the lists and figures of Chironomidae. In the first place, we note that while midge-larvae have increased greatly here since 1915, in spite of the disappearance the while of half a dozen formerly common species of clean-bottom habit, yet no distinctly pollutional species has invaded this section since 1915, and only two forms of wide range or doubtful preference (*Chironomus lobiferus* Say and a species very close to *C. decorus* Joh.) are new here since the 1913—1915 period. Further, it will be noted that more than half of the increase in weight-valuation of Chironomidae in the river below Havana in the five years preceding 1920 is not due to these two newly introduced tolerant forms, if indeed they are both so, but follows from the multiplication here recently of three of the large larvae of clean-bottom habit which were common to abundant in the lakes above Havana in and before 1915, but which have since been exterminated in that range, with the exception of Quiver Lake. These three species (*C. tentans* F., *C. ferrugineovittatus* Zett., and *Procladius concinnus* Coq.) occurred in good numbers in 1920 in this section of the river wherever there was mud, and the sharp reversal in their distribution, from lake and backwater above Havana to river below Havana, seems to lend some support to the supposition that their recent appearance and rapid multiplication in their new range is in some manner connected with their disappearance from the old one.

MIDGE LARVAE (CHIRONOMIDAE) OF BOTTOM MUDS OF ILLINOIS RIVER BELOW
HAVANA,* 1913—14 TO 1920—JULY—OCTOBER

1. *Tolerant species or species of doubtful preference that have come in since 1913—14.*
Chironomus lobiferus Say. Present, 1920.
C. sp. near decorus Joh., No. 2. Abundant, 1920.
2. *Cleaner-water species that have dropped out since 1913—14.*
Palpomyia longipennis Lw. Present in 1913—14.
Tanypus monilis L. Present in 1913—14.
Chironomus dux Joh. Present in 1913—14.
C. digitatus Mall. Present in 1913—14.
Cricotopus trifasciatus Panz. Present in 1913—14.
Cricotopus sp. Present in 1913—14.
3. *Cleaner-water species that have come in since 1913—14.†*
Procladius concinnus Coq. Common, 1920, shallow zones.
Chironomus ferrugineovittatus Zett. Present, 1920, 4—7-foot zone.
C. tentans F. Common, 1920, chiefly in shallow zones.
4. *Tolerant or indifferent species that has dropped out since 1913—14.*
Chironomus decorus Joh. Present, 1913—14.

* Occurrence in 1913—14 principally below Beardstown; in 1920, 2.5 miles below Havana to 1.5 miles below head of Grand Island.

† All these species were present or common both in the river and the lakes above Havana, 1913—14, but were not found in either of those ranges last year, if the occurrence of *C. ferrugineovittatus* in Quiver Lake in 1920 be excepted.

While sludge-worms showed some increase in this section since 1915, their gain was slight and of very small moment compared with the increases shown in five years either in the Peoria section or in the reach just north of Havana. All of the small oligochaetes taken, however, belonged to genera of the family Tubificidae, about half of them being species of the genus *Tubifex*.

Though, as already mentioned, a marked increase in variety as well as an actual average increase in poundage since 1915, is plainly shown by the group of "other insects, etc.", there were a good many eliminations from the lists even in this group in the five years preceding 1920. Non-insect groups or insects other than Chironomidae that were readily taken in this part of the river in 1913—1915 but that did not appear in collections in 1920, include the little crustaceans *Asellus* and *Hyalella*; two or three species of Ephemeridae; two species of Corixidae; adult bottom-beetles of the genus *Stenelmis*; several fresh-water sponges; and at least one genus and species of Bryozoa, namely, *Paludicella* sp., which was formerly common on almost all the dead shells of Unionidae.

Total average-valuations of all small bottom-animals for this section in 1920—30 pounds per acre in the channel, 89 pounds in the 4—7-foot zone, and 526 pounds in the 1—3-foot zone—exceed 1915 figures in the first and last instances; while in the 4—7-foot zone they were well under the older valuations, as shown in the table following. Both in the channel and in the 1—3-foot zone the decreases in snails were more than made up for by increases in midge larvae and "other insects" and miscellaneous species. In the 4—7-foot zone the increase in snails was greater and the increase in Chironomidae and minor insects, etc., less, either relatively or absolutely or both, than in the 1—3-foot zone. To what extent these zonal differences in distribution both of the total bottom fauna and its subdivisions may be connected with differences in wholesomeness of conditions on different sections of the river floor, or to what extent they may reflect mere casual migration of surviving species following a general mortality, our present data give us no certain basis for an opinion.

ALL SMALL BOTTOM-ANIMALS, HAVANA TO GRAND ISLAND*, 1915 AND 1920

1. Average numbers per square yard

	Channel		4-7-ft. zone		1-3-ft. zone	
	1915	1920	1915	1920	1915	1920
Viviparidae and Pleuroceridae	6	10	73	9	99	104
Sphaeriidae	6	2	84	12	89	12
Amnicolidae, Valvatidae, etc.	0	0	4	0	2	0
Chironomidae	trace	36	2	170	6	244
Oligochaeta	0.5	2	9	33	0	24
Other insects, worms, Crustacea, etc.	3	78	20	27	12	429
Grand total	15	128	192	251	208	813

* To 1 mile below head of Grand Island in 1920; to head of Grand Island in 1915.

2. Average pounds per acre

	Channel		4-7-ft. zone		1-3-ft. zone	
	1915	1920	1915	1920	1915	1920
Viviparidae and Pleuroceridae	16	9	235	11	386	312
Sphaeriidae	3	1	42	6	44	6
Amnicolidae, Valvatidae, etc.	0	0	0.1	0	0.1	0
Total snails	19	10	277	17	430	318
Chironomidae	trace	6	0.3	45	1	122
Oligochaeta	0.1	trace	0.3	1	0	1
Other insects, worms, Crustacea, etc.	3	14	5	26	4	85
Grand total	22	30	283	89	435	526
Per cent. snails	86.3	33.3	97.8	19.1	98.8	60.4

**Three all-Bottom-land Lakes and one Sand-beach Lake between
Liverpool and Havana
(Mile 199.0—207.0 below Lake Michigan)**

The season's collections in Liverpool, Dogfish, and Thompson lakes in 1920 were taken in early September in almost uniformly muddy bottom between near shore and the six-foot line. All of the stations visited in these lakes at that time were in open water, though a large part of the same area in all of the lakes and most of it in some of them was well supplied with coarse vegetation between 1913 and 1915. Mud, spongy with gas, was taken at two of the stations in Liverpool Lake and there was more or less foulness of odor and abundant bubbling at all stations in all three lakes. While odors were particularly bad in the Liverpool Lake samples, they were not nearly so bad either in Thompson or Dogfish. In the last-named lake there was a light covering of lighter colored silt over older gassy black mud, the topmost layer having its origin less than six months before in the dredging operations for an agricultural drainage district immediately north.

In Quiver Lake the samples from muddy bottom in open water (mostly in the old vegetation zone, as in the other three lakes) all had bad odor and gave off abundant bubbles. Samples from the mud and mud and shell bottom in the deeper "channel" through this lake, and from the mud and sand near the east beach were decidedly less gassy and more wholesome in odor.

While not less than six families of snails, represented by about a dozen species, were common or abundant in 1913—1915 in each of these four lakes, no snails at all were taken in Liverpool or Dogfish lakes in September, 1920, and in Thompson Lake only a small number of a single species. In Quiver Lake, as in Dogfish and Liverpool lakes, no snails at all were found in the shallower, more stagnant open portion less than six feet in depth; but in the "channel" fed by Quiver Creek, and toward shore on the east side, good numbers of *Pleurocera*, and small numbers of *Musculium transversum* and *Vivipara subpurpurea* were taken.

The table following shows the detailed changes in the composition of the snail fauna in Thompson Lake only. It represents very well, also, with only slight alterations, the changes that have taken place in Dogfish and Liverpool lakes, and in the muddy portion of Quiver, the principal requirement being to transfer the little surviving sphaeriid at the head of the table to the list of species underneath that have dropped out since 1913-1915.

SNAIL FAUNA OF BOTTOM MUDS OF THOMPSON LAKE, 1913—1915 TO 1920

I. *Species surviving in 1920.*

1. Sphaeriidae	Musculium transversum	Present, 1920, in very small numbers in Thompson Lake only out of four lakes examined. Was common to abundant in all lakes of this district, 1913—15.
----------------	-----------------------	---

II. *Species that have dropped out since 1913—15, and distribution in that period.*

1. Viviparidae	1. Campeloma subsolidum	Common, all zones.
"	2. Lioplax subcarinata	Common, deeper water.
"	3. Vivipara contectoides	Abundant locally; present nearly everywhere.
"	4. V. subpurpurea	Infrequent.
2. Amnicolidae	5. Amnicola emarginata	Common locally.
"	6. Somatogyrus sp.	Infrequent.
3. Valvatidae	7. Valvata bicarinata	Common to abundant.
"	8. V. tricarinata	" " "
4. Planorbinae	9. Planorbis trivolvris	Common, shallower zones.
5. Physidae	10. Physa sp.	" " "
6. Sphaeriidae	11. Musculium jayanum	Scattered occurrences.
"	12. Pisidium sp.	Abundant locally.

The drop in average weight-valuation of the snail fauna in these four lakes, except in the less injured portions of Quiver Lake mentioned, amounts to little short of total disappearance—namely, from 122—363 pounds per acre to nothing at all in Liverpool, Dogfish, and the muddier, more stagnant portion of Quiver; and from 409 pounds to 4 pounds per acre in Thompson.

The decrease in snail poundage since 1915 in Thompson Lake, where it is in the least ratio, was 99.1 per cent., which is greater even than the percentage decline in the river channel between Liverpool and Havana. In the Quiver Lake channel the drop in valuation figures since 1915 is only about 70 per cent., leaving an average of 248 pounds per acre in the limited range in September, 1920. Shoreward on the muddy side of Quiver Lake an average valuation of 109 pounds per acre in 1920 stands without a separate 1914 or 1915 figure for comparison.

SNAIL FAUNA OF BOTTOM MUDS, FOUR LAKES NORTH OF HAVANA, 1914-1915 TO 1920
 AVERAGE NUMBER PER SQUARE YARD
 I. Mud Bottom, 2 to 6 Feet

	1914-1915				1920			
	Viviparidae and Pleuroceridae	Sphaeriidae	Valvatidae, Amnicolidae, etc.	Total snails	Viviparidae and Pleuroceridae	Sphaeriidae	Valvatidae, Amnicolidae, etc.	Total snails
Liverpool Lake*	23	17	10	50	0	0	0	0
Thompson Lake*	113	153	98	364	0	8	0	8
Dogfish Lake†	68	138	164	370	0	0	0	0
Quiver Lake†	85	50	74	209	0	0	0	0

II. Sandy or Sand and Mud Bottom

Quiver Lake "channel"	160	0	0	160	169	0	0	169
Quiver Lake, sandy shore, east side	common	0	0	common	91	3	0	94

* Figures in 1914-15 columns are for year 1915.

† Figures in 1914-15 columns are for year 1914.

In Thompson, Dogfish, and Liverpool lakes in September, 1920, not only was it true that not a single definitely recognized clean-water chironomid of the previous period (1913—1915) was found surviving in the larval or pupal stage in the muds, but, as well, the lists both of new entrants and survivals, of whatever habit of preference, showed up very meagerly both in variety and abundance as compared with the lists and figures for the Peoria Lake district and the river just above Havana. Both in Thompson and Liverpool lakes, however, there did appear last year small numbers of one new form of possibly tolerant habit, this opinion being based only on its taxonomic nearness to *Chironomus decorus* Joh. In neither of these two lakes nor in Dogfish Lake was there any evidence of the recent intrusion of species of distinctly pollutational habit, while in the muddier portions of Quiver Lake two of the older clean-water Chironomidae (*C. ferrugineovittatus* Zett., and *Palpomyia longipennis* Lw.) that were formerly present in all the lakes of this group were the principal components of the 1920 chironomid population in September.

The changes in total chironomid poundages since 1914—1915 in all of these four lakes except Quiver, quite contrary to those in the Illinois River opposite, are in the direction of decrease rather than increase, the average yields in 1920 (9 pounds per acre in Dogfish, 4 pounds in Thompson, 2 pounds in Liverpool) being in no case over 50 per cent. of the 1914—1915 yields, and at the lowest only 5 per cent.; while they are only 5 to 7 per cent. of the 1920 yields of Chironomidae from the river muds between Liverpool and Havana. The discrepancies between lake and river figures for immature midges in this portion of the river system, contrasting with essentially similar changes both in river and lake in the snail group, may be concerned with the fact of the greater ease of spread of the eggs and larvae of the midges down stream with the advance of pollution than by wing across the timbered ridges that separate the river from the lakes. At any rate, two of the principal pollutational or tolerant species contributing to last year's large river poundages of Chironomidae just above Havana (*C. plumosus* Linn., and *C. decorus* Joh.) did not up to that time appear to have been successful in making the trip.

MIDGE LARVAE (CHIRONOMIDAE) OF BOTTOM MUDS OF
LIVERPOOL, DOGFISH, QUIVER, AND THOMPSON LAKES, 1913—1914
TO 1920—JULY—OCTOBER

1. *Tolerant species or species of doubtful preference that have come in since 1913—14.*

Chironomus sp. near *decorus* Joh., No. 2. Common, 1920, Thompson Lake only.

C. sp. near *decorus* Joh., No. 1. Common, 1920, Liverpool Lake only.

2. *Formerly common cleaner-water species still surviving in 1920.*

Chironomus ferrugineovittatus Zett. Present, 1920, Quiver Lake only.

Palpomyia longipennis Lw. Present, 1920, Quiver Lake only.

3. *Cleaner-water species that have dropped out since 1913—1914.*

Tanytus monilis L. Common, all lakes, 1913—1914.

Procladius concinnus Coq. Common, all lakes, 1913—1914.

P. sp. near *concinnus* Coq. Common, most lakes, 1913—1914.

Chironomus tentans F. Abundant, all lakes, 1913—1914.

C. modestus Say. Common, all lakes, 1913—1914.

4. *Tolerant species that have dropped out since 1913—1914.*

Chironomus lobiferus Say. Present, 1913—1914, Thompson Lake only.

C. decorus Joh. Present, 1913—1914; lake not stated.

MIDGE LARVAE (CHIRONOMIDAE) OF BOTTOM MUDS,
LAKES NORTH OF HAVANA, 1914—15 AND 1920—JULY—OCTOBER
I. Mud bottom, 2 to 6 feet

	Number per square yard		Pounds per acre	
	1914—1915	1920	1914—1915	1920
Liverpool Lake*	38	14	26	2
Thompson Lake*	12	24	8	4
Dogfish Lake†	60	24	30	9
Quiver Lake†	33	54	6	12
Ill. River. Liverpool to Havana, 1915, for comparison	Channel, 0 4—7 ft., 0	950 225	0 0	164 45

II. Sandy or sand and mud bottom

Quiver "channel" *	0	0	0	0
Quiver Lake, sandy shore east side	Not separately counted	6	Not separately valued	1

* Figures in 1914—15 columns are for year 1915.

† Figures in 1914—15 columns are for year 1914

The increase in sludge-worms in Liverpool, Dogfish, and Thompson lakes since 1915, though comparing with decreases in midge larvae, as already mentioned, was greater even than the increase in these worms in the Illinois River channel opposite, apparently proving that this group has been able to accompany the pollution inward from the river, even if the midges have not. The sludge-worms in the first-named lake amounted in figures per square yard to 389 in September, 1920, as compared with none at all in the collections of July—October, 1915; and in pounds per acre to 14 in 1920 as against none in the former period. In Quiver Lake in 1920, both in the muddy portion and in the sandier areas, while the increase in small oligochaetes since 1915 is evident enough, it is very much less than in the other three lakes. The small oligochaetes taken in Liverpool, Dogfish, and Thompson in 1920 were nearly all Tubificidae and a great majority of them belonged to the genus *Tubifex*. In the Quiver Lake samples, on the other hand, small non-tubificid *Oligochaeta* were visibly more common than Tubificidae.

SLUDGE-WORMS, (PRINCIPALLY TUBIFICIDAE),
LAKES NORTH OF HAVANA, 1914—15 AND 1920

I. Mud bottom, 2 to 6 feet

	Number per square yard		Pounds per acre	
	1914—1915	1920	1914—1915	1920
Liverpool Lake*	0	389	0	14
Thompson Lake*	0	128	0	4
Dogfish Lake†	0	128	0	4
Quiver Lake†	12	48	0.4	2
Ill. River, Liverpool to Havana, 1915, for comparison	Channel, 0 4—7 ft., 0	89 4	0 0	3 0.1

II. Sandy or sand and mud bottom

Quiver Lake "channel" *	0	0	0	0
Quiver Lake, sandy shore east side	Not separately counted	30	Not separately valued	1

* Figures in 1914—1915 columns are for year 1915.

† Figures in 1914—1915 columns are for year 1914.

Not only in Thompson, Dogfish, and Liverpool lakes in 1920, but in Quiver Lake also in its muddy part, we found nothing at all surviving out of a list of some ten or twelve families of minor insects and miscellaneous small bottom-animals other than the groups already passed in review that were common in all of these lakes in 1914—1915. Though this item of loss in the lakes near Havana has been greater since 1915 than in the river just above Havana, the decrease in poundage therein in comparison to totals of all small bottom-animals has not been very large, the figures that follow showing that at the best the total weight of "other insects, etc.," in the bottom muds of these lakes in 1914—1915, did not run to twenty pounds per acre. In the Quiver Lake "channel" and in the sand and mud toward the beach side our collections showed leeches, Bryozoa, larvae of caddis-flies, and nymphs of Odonata in good variety and number, the "channel" average in 1920 (32 pounds per acre) being larger than in 1915.

"OTHER INSECTS," WORMS, CRUSTACEA, ETC., OF THE BOTTOM MUDS,
LAKES NORTH OF HAVANA, 1914—15 AND 1920

I. Mud bottom, 2 to 6 feet

	Number per square yard		Pounds per acre	
	1914—1915	1920	1914—1915	1920
Liverpool Lake*	16	0	3	0
Thompson Lake*	32	0	5	0
Dogfish Lake†	22	0	13	0
Quiver Lake†	83	0	19	0

II. Sandy or sand and mud bottom

Quiver Lake "channel" *	26	36	3	32
Quiver Lake, sandy shore, east side	Not separately counted	15	Not separately valued	8

* Figures in 1914—1915 columns are for year 1915.

† Figures in 1914—1915 columns are for year 1914.

The decrease in average valuation of all small bottom-animals in the four lakes since 1915, with the sandy portions of Quiver Lake omitted, has been in ratios quite similar to those of average decline in the period in

the river opposite, viz., 89.2 to 97.4 per cent. Such a decrease, on a base of only 150 to 400 pounds per acre as of 1915, evidently leaves a much smaller residue in the lakes than remains in the river of the enormously greater poundages that were there in and before 1915. Average total poundages in these four lakes, with the exceptions mentioned, in fact amounted to only 12 to 16 pounds per acre in 1920 as compared with 40 pounds and 87 pounds in the channel and 4—7-foot zone of the river opposite, and with 5,180 pounds and 2,122 pounds in the corresponding river zones in the former period. Compared with this enormous falling off in yields in the three all-bottom-land lakes and the stagnant portion of Quiver, the decrease in poundage of all bottom-animals in the mud-sand-and-shell bottom of the Quiver Lake channel amounted to only 65 per cent. since 1915, leaving an average of 280 pounds per acre in September, 1920. As in the river just above Havana, the great part of the decline in lake yields of all bottom-animals since 1914—1915 has resulted from the destruction of the snails, the percentage of total-weight valuations contributed by the small Mollusca dropping during the five or six-year period from 97.2 to 33.3 per cent. in Thompson Lake, and in the other three lakes, excepting the sandy portions, from 81—93 per cent. to none at all.

ALL SMALL BOTTOM-ANIMALS, LAKES NORTH OF HAVANA.
1914—15 AND 1920

1. Average total valuation, pounds per acre, and percentage by weight of average total hauls contributed by snails

I. Mud bottom, 2 to 6 feet

	Pounds per acre		Per cent. decrease, 1914—15 to 1920	Per cent. snails, by weight	
	1914—15	1920		1914—15	1920
Liverpool L.*	149	16	89.2	81.8	0
Thompson L.*	472	12	97.4	97.2	33.3
Dogfish L.†	397	14	96.7	89.4	0
Quiver L.†	388	14	96.3	93.6	0

(Continued on next page)

II. Sandy or sand and mud bottom

Quiver Lake "channel" *	803	280	65.1	99.6	88.5
Quiver Lake, sandy shore, east side	Not separately valued	121			

* Figures in 1914—1915 columns are for year 1915.

† Figures in 1914—1915 columns are for year 1914.

2. Composition, by weight, of the grand totals,
all mud bottoms, 2 to 6 feet, pounds per acre

	Liverpool Lake		Thompson Lake		Dogfish Lake		Quiver Lake	
	1915	1920	1915	1920	1914	1920	1914	1920
Viviparidae and Pleuro- ceridae	117.0	0	437.9	0	336.0	0	329.7	0
Sphaeriidae	3.7	0	15.6	4.0	10.1	0	16.7	0
Amnicolidae, Valvatidae, etc.	0.5	0	5.3	0	9.0	0	16.7	0
Chironomidae	25.6	2.2	8.3	3.6	29.6	8.6	5.5	12.3
Oligochaeta	0	13.6	0	4.5	0	4.4	0.4	1.6
Other insects, worms, Crustacea, etc.	2.6	0	5.0	0	12.8	0	19.3	0
Grand total	149.4	15.8	472.1	12.1	397.5	13.0	388.3	13.9

While at the lower gages of the drier months of 1913 and 1914 not less than 40 per cent. of the area of Thompson Lake, probably fully 30 per cent. of Liverpool, and more than 50 per cent. of Dogfish and Quiver lakes, was well filled with mixed aquatic vegetation, in 1919 and 1920 at substantially the same gages and temperatures, it is certain that for any of these lakes 2 per cent. would have been an extravagant figure to set

as an estimate of the ratio of weeded to total area. In July or August, 1920, two per cent. would have meant about 100 acres of vegetation in Thompson at the height of the growth period, while as a matter of fact a careful examination of the lower two-thirds of this lake, which was weedier than the upper third five to seven years ago, disclosed less than two acres that could be called even partially weedy. Over a total of some thousands of acres in these four lakes since 1913—1915, the plants have disappeared as completely as dry stubble before a fire, and our observations in Peoria Lake and reports from fishermen and other river men concerning lakes that we have not entered since 1915 indicate that the destruction has been little if any less complete everywhere in the backwaters between Chillicothe and Havana.

In the scattered remnant-bunches of *Potamogeton pectinatus* still growing in Thompson Lake on the small sandy area of bottom at Warner's Cut in September, 1920, it was impossible to collect by the quantitative method used in 1914 and 1915. It is, however, clear that the former enormous weed-animal yields—over 2000 pounds per acre for 40 to 50 per cent. of the total lake and pond acreage in this district six or seven years ago—have vanished with the water plants, and that any figures that could have been obtained last year by any method would stand as wholly negligible in comparison with the old averages. Unless, in fact, we assume, as is probably the case, that in the spring and earlier summer months there is at least a somewhat greater variety and abundance both of bottom and shore animals than was shown by the examinations made in September, 1920, it is hard to understand how the surviving food and game fishes that find their principal food in the small invertebrate fauna can continue to subsist without evident general emaciation. Both the fact that they were not yet generally emaciated in the summer of 1920, and the very low indicated residues of bottom and shore animals after six or seven months feeding at the same time may, from another view-point, be taken as evidence that the food supplies are in recent seasons being *fed down* to an unusually low point before autumn; or, in other words, that the heavy declines in midsummer valuation-figures of *all* small bottom-animals since 1915 may not be quite so altogether an effect of the advance of sewage pollution as are the indicated changes in the *composition* of the fauna.

Stewart Lake, an all-Bottom-land Lake of the Shallower Type, twenty Miles south of Havana

(Mile 224.0—226.0 below Lake Michigan)

The first impression one receives upon going into Stewart Lake and handling samples of its muds, after a week of work in the barren expanses of gas-filled lake and river floor twenty miles north, is one of large and distinct improvement in the odors and physical appearance of

the muds, and in the comparative amount and variety of the old mixed aquatic vegetation still surviving. Though the evidence furnished by the state of the bottom fauna itself in this lake in 1920 was also in some directions indicative of a much more nearly normal condition than in the lakes north of Havana at the same time, the disappearance from Stewart Lake since 1915 of a large part of its old bottom fauna tells as surely of an advance of pollution thus far southward at some time or other since 1915. The evidence of extinction of almost the whole snail fauna, along with the fairly wholesome condition of the bottom muds in 1920, is, I think, probably to be taken as proof that the destruction of the snails took place a considerable time back, and that a wave of pollution such as accomplished it has not carried so far south in all recent flood seasons. The effect of the high Spoon River bar and the large natural impounding area just north of Havana in favoring sedimentation are probably more important than the eighteen or twenty miles of additional distance in protecting Stewart Lake from the regular invasions of putrescible settling suspended matter that have apparently been affecting Liverpool, Thompson, and other lakes in the Liverpool—Havana district every spring in recent years.

A snail list for Stewart Lake, 1915 to 1920, is not essentially different from one for Thompson Lake, showing the same single species (the little sphaeriid *Musculium transversum*) surviving in small numbers; and a list of around thirteen species, representing seven families, that have dropped out since 1915. While Stewart Lake was not even several years ago a heavy bottom-fauna producer, either on the snail side or otherwise, as compared with the lakes north of Havana, showing only 66 pounds per acre of snails and 74 pounds of all small bottom-animals in 1915, the 1920 figures of only 2 pounds per acre of snails (one species) and 28 pounds of all other bottom-animals look small enough even in comparison with the older figures to show that something has happened.

In the group of "other insects, etc.," Stewart Lake last year made fully as bad a showing as in small Mollusca, neither Bryozoa, leeches, small bottom-Amphipoda or Isopoda, Corixidae, Trichoptera, or Ephemeridae—all of which were found commonly in small numbers at collecting stations in this lake six or seven years ago—appearing in 1920 in any bottom collection.

Perhaps the best biological indication of a wholesomer condition of the mud in this lake than in those farther north, next after the more thriving condition of the vegetation, is the survival here in good numbers of a few of the more sensitive species of Chironomidae which have been completely exterminated in the lakes north of Havana except Quiver, and the failure of the sludge-worms to show as marked increase as in the lakes farther north. The total number of small oligochaete worms increased in Stewart Lake between 1915 and 1920 only from three to twelve per square yard—a negligible increase as compared with, for ex-

ample, 0 to 389 per square yard in Liverpool Lake and 0 to 128 per square yard in Thompson Lake in the same period.

While two of the formerly common clean-water midges, *Chironomus ferrugineovittatus* Zett. and *Procladius concinnus* Coq. were still common in the lake in 1920 and, along with a new entrant, also at least not of polluttional habit, made up the bulk of the large increase in Chironomidae in collections in this lake since 1915, the full list of species for 1920 is much smaller than formerly, and calls attention to several species, some of which are partial to cleaner bottom, that have dropped out since the earlier period.

Though separate collections of the small weed-animals were not taken in 1913—1915 in Stewart Lake, as in Thompson Lake and others just north of Havana, it is well enough known to us from general observations that there was a rich fauna of that kind here in those years. Since much the richest portion of the old weed-fauna areas in the Illinois valley lakes was found in the Potamogeton or Ceratophyllum associations, and the poorest in the Nymphaea and Nelumbo beds, and as Stewart Lake lost a very much larger proportionate amount of its Potamogeton and Ceratophyllum than of its lilies in the five years preceding 1920, it is plain that the loss in the small weed-fauna of the lake has been very large in the period, though smaller than in the lakes twenty miles north.

A table recapitulating all our 1920 distributional data on the larval midges from the river and lakes between Chillicothe and Browning follows the short lists of species from Stewart Lake next presented, and with them concludes the present section.

MIDGE LARVAE (CHIRONOMIDAE) OF BOTTOM MUDS,
STEWART LAKE, 1913—1914 TO 1920

1. *Cleaner-water species or other species present in 1913—1915 that have dropped out since then.*

Palpomyia species, 9 mm.
Tanypus monilis L.
Procladius culiciformis Lw.
Tanypus dyari Coq.
Chironomus lobiferus Say.

2. *Cleaner-water species new to the lake since 1913.*

Palpomyia longipennis Lw. Common, 1920.

3. *Cleaner-water species common both 1913—1914 and 1920.*

Procladius concinnus Coq.
Chironomus ferrugineovittatus Zett.

Illinois River and Peoria Lake,
Chillicothe to Havana:

	More pollutional or tolerant species						More non-pollutional species						Total, including species of uncertain status, not including preceding columns		
	<i>Chironomus dicorus</i> Job.	<i>Tanypterus</i> Cogh.	<i>Chironomus plumosus</i> Linn.	<i>Chironomus plumosus</i> Linn., var.	<i>Chironomus crassicaudatus</i> Mall.	<i>Chironomus muticus</i> Job.	<i>Chironomus fringens</i> Job.	<i>Chironomus lobiferus</i> Say	<i>Chironomus</i> sp., near <i>decorus</i> Job., No. 1	<i>Chironomus</i> sp., near <i>decorus</i> Job., No. 2	<i>Chironomus tentans</i> F.	<i>Chironomus ferugineus</i> Zett.		<i>Palpomyia longipennis</i> Lw.	<i>Procladius cornutus</i> Cogh.
1. Chillicothe to Spring Bay (upper lake)	channel	800	16												1,216
	4—7-ft. zone	220	192	130											554
2. Mossville to Al Fresco Park (middle lake)	channel		12												36
	4—7-ft. zone		3	60											201
	1—3-ft. zone				84										84
3. Workhouse to Liberty Street (lower lake)	channel			139	37	+	+	+							244
	4—7-ft. zone			248	60	+	+	+							332
	1—3-ft. zone			37											198
4. Liverpool to Havana	channel			20				100	600	65					950
	4—7-ft. zone			20					174	10					225
All-bottom-land lakes above Havana, depths 2—6 feet: Liverpool Lake									10						15
	Dogfish Lake														24
Thompson Lake									16						24
Illinois River, 2 mi. below Havana to 1.5 mi. below head of Grand Island	channel							1		1					36
	4—7-ft. zone								95	13	37				170
	1—3-ft. zone								120	8				96	244
Sand beach lake above Havana: Quiver Lake, depths 2—6 feet												12	24		54
Shallow, all-bottom-land lake 19 miles below Havana: Stewart Lake, depths 2—5 feet												20	16	38	74

* Plus sign means common, on basis of adults and pupal exuviae.

ALL SMALL BOTTOM-ANIMALS, STEWART LAKE, 1915 AND 1920

MUD BOTTOM, 2 TO 5 FEET

	Number per square yard		Pounds per acre	
	1915	1920	1915	1920
Viviparidae and Pleuroceridae	21	0	41	0
Sphaeriidae	32	4	13	2
Amnicolidae, Valvatidae, etc.	37	0	12	0
Total snails.....			66	2
Chironomidae	8	74	2	28
Oligochaeta	3	12	0.1	0.4
Other insects, worms, Crustacea, etc.	43	0	6	0
Grand total.....			74	30
Percentage of snails			89.1	6.5

Estimated Reduction of Midsummer Surplus Stocks in the Combined Acreage between Chillicothe and Lagrange Dam (103 Miles) since 1914—1915

While the necessarily restricted range of our bottom-and weed-fauna survey of 1920, compared with that of July—October, 1914 and 1915, leaves more gaps to be supplied by estimate in any general comparison than is perhaps best, it has seemed worth while, as a conclusion to the present paper, to make some computations of the approximate total loss since 1914—1915 in surplus bottom- and weed-fauna stocks as of the midsummer period for the entire acreage of river and lakes in the formerly enormously rich middle Illinois Valley district between the head of Peoria Lake and the Lagrange dam. These calculations have involved a partial reapportionment, by estimate largely, both of acreages and of acre-yields, as of 1908—1915, as published in a preceding paper,* these

* The Small Bottom and Shore Fauna of the Illinois River and its Connecting Lakes, Chillicothe to Grafton: its Valuation; its Sources of Food Supply; and its Relation to the Fishery. By R. E. Richardson. Bul. Ill. Nat. Hist. Surv., Vol. 13, Art. XV. 1921.

being here estimated as actual, outside of levees, and not as in the virgin valley—for the purpose of comparison with the 1920 data rather than with the fish-yield figures of 1908; and involving as well, the application in some cases of both river and lake acre-yield-figures for limited areas studied in 1920 to much larger acreages not collected in that year. For these reasons, only general results are given here, and tabulation is avoided as giving too much of an air of certainty to figures that are at the best only approximations.

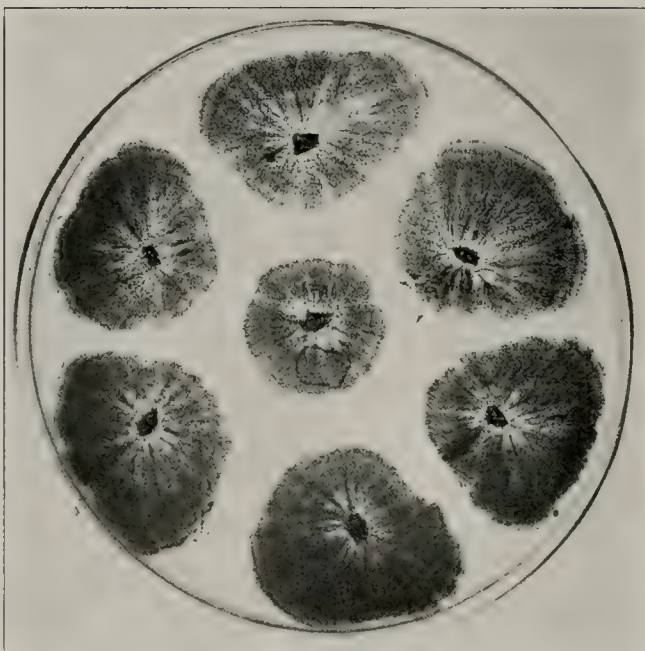
In the 60.5 miles between Chillicothe and Havana in July—October, 1914—15 it appears, then, that there were surplus stocks of both bottom and weed animals, after deduction of shell weight, amounting to around 27,500,000 pounds in a combined open river and lake acreage, including Peoria Lake of about 29,000 acres at an approximate gage of ten feet, Peoria, or eight feet, Havana. Of this total I have estimated that about 2,700,000 pounds were in the bottom muds of the river and the wide waters of Peoria Lake between Chillicothe and the dam at Copperas Creek; about 3,800,000 pounds in the river muds between Copperas Creek dam and Havana; and about 3,000,000 pounds on the lake and other backwater floors between Copperas Creek and Havana. Considerably more than half of the total, that is, over 18,000,000 pounds (65 per cent.) of it, seems to have been made up of the small weed-living species, of which Peoria Lake apparently furnished more than 4,000,000 pounds a few years ago, and the rich lakes between Copperas Creek dam and Havana, around 14,000,000 pounds.

Applying to these same acreages such average weights per acre as are suggested by the findings of August—September, 1920, we note first an estimated reduction since 1915 in the bottom fauna of Peoria Lake and adjacent river between Chillicothe and Copperas Creek that amounts roughly to 50 per cent., and that affects about 10,000 acres at the lower gages of the ten years preceding 1920. Next are calculated reductions of 92 to 93 per cent. in the bottom fauna of some 1,400 acres of river and some 17,000 acres of lakes between Copperas Creek dam and Havana; and, last, reductions to practical nullity in the case of the acre-yield figures of small weed-animals both of the weedy acreage of Peoria Lake, estimated at 2,000 acres in 1910—1914, and of the one-time approximate 10,000 acres of shallow weed-area in the lakes between Copperas Creek dam and Havana. The total loss in poundage of surplus stocks between Chillicothe and Havana in five years appears indeed to have surpassed 25,500,000 pounds, or to have amounted on the average for both river and lakes, including both bottom and weed populations, to over 93 per cent. The extent of the loss is better appreciated when it is known that it is usual to figure that the weight of fish living on animal food can be increased about one pound for each five pounds of such food eaten. From this view-point the loss in potential fish-yield apparently stands at something like 5,000,000 pounds yearly for the section, if also it be true, as is

generally assumed, that stocks of the kind in question in the run of years at least reproduce themselves in weight once annually.

Below Havana we lack data for carrying out computations in the detail or with anywhere near the exactness attempted for the 60-mile section to the north, particularly in the case of the bottom and weed fauna of the lakes, having collected in only one of these in 1920. We note, first, of the 4,500 odd acres of river between Havana and the dam at Lagrange, an apparent slight gain over 1915 in the bottom yields, which is, however, probably no greater than the normal error to be expected with the apparatus and methods used. Offsetting this gain further, to the point in fact of rendering it negligible, are suggested losses of enormous size since 1914—1915 both in the bottom and weed fauna of the lakes and other backwaters in the 42.5 miles, which, combined, seem to have amounted to fully half the total stocks in the entire river and lake acreage open a little more than five years ago, or to more than twenty times the total bottom-fauna stocks of the section. This result, or a loss in the lake weed- and bottom-fauna of around 9,000,000 pounds, is simply arrived at if we estimate the loss in both the bottom- and weed-fauna stocks since 1915 at only 50 per cent. If we base conclusions for the entire acreage between Havana and the dam, on the recorded kind and extent of change in Stewart Lake since 1915 we must estimate the combined loss in both bottom and weed animals as even greater than 50 per cent., since it appears that on the weed-fauna side both the acreage and its average yield have probably been reduced that much. And as most of the lake acreage between Havana and the dam at Lagrange has since 1915 been north rather than south of the lower end of Stewart Lake, and therefore probably equally with it exposed to invasion by foul water and sediments, the estimate of a nine-million-pound loss in this district since 1915 may be allowed to stand as a minimum probable figure.

Combining a minimum loss in the first 42.5 miles south of Havana of 9,000,000 pounds with one of 25,500,000 pounds between Chillicothe and that point, we have, then, it seems, to reckon on not less than 34,500,000 pounds total reduction in the midsummer stocks of small bottom- and weed-animals in five years in about 103 miles; or, putting it another way, on about 7,000,000 pounds potential fish-yield missing from any new calculations we wish to make about the more recent value of a 103-mile section of the Illinois River fishery that was, only a few years ago, among the richest of its kind in the fresh-water stream systems of the world, being then uninjured, so far as could be seen, by the increasing pollution from the population and industries to the north that has recently so nearly overwhelmed it. It will be noted that 7,000,000 pounds is little less than a third of the largest total fish-catch ever taken from the entire Illinois River (catch of 1908), more than half of estimated total yields in 1912 and 1913, and not improbably more than the total yield for the whole year 1920.



Original isolations of the foot-rot *Helminthosporium* made in May, 1919, from bits of tissue from wheat grown in Madison county, Illinois.

STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION
DIVISION OF
NATURAL HISTORY SURVEY
STEPHEN A. FORBES, Chief

Vol. XIV.

BULLETIN

Article V.

The Helminthosporium Foot-rot of Wheat, with
Observations on the Morphology of
Helminthosporium and on the
Occurrence of Saltation
in the Genus

BY

F. L. STEVENS

PRINTED BY AUTHORITY OF THE STATE OF ILLINOIS

URBANA, ILLINOIS
June, 1922

STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION

W. H. H. MILLER, *Director*

BOARD OF
NATURAL RESOURCES AND CONSERVATION

W. H. H. MILLER, *Chairman*

WILLIAM TRELEASE, *Biology*
JOHN M. COULTER, *Forestry*
ROLLIN D. SALISBURY, *Geology*
WILLIAM A. NOYES, *Chemistry*

JOHN W. ALVORD, *Engineering*
KENDRIC C. BABCOCK, *Representing the*
President of the University of Illi-
nois

THE NATURAL HISTORY-SURVEY DIVISION

STEPHEN A. FORBES, *Chief*

CONTENTS

	PAGE
Introductory	77
I. A foot-rot of wheat and its causal fungus:	
Symptoms	78
Fungi present	78
Growth of the causal fungus on various media	79
Various agars as media	80
Summary concerning growth on agars	85
Rice and similar substances as media, with special note of color phenomena	86
Summary concerning growth on rice and similar substances	88
Miscellaneous vegetable media	88
Summary concerning the foregoing vegetable media	90
Cereal shoots grown from aseptic seeds as media	90
Environmental factors which induce variation	91
Quantity of nutriment	91
Inhibitory influences	93
Humidity of media	93
Humidity of air	94
Temperature relations	98
Light	99
Carbohydrates	100
Nutrients as affecting conidial length, septation, and shape	101
Summary concerning environmental factors which induce variation	102
Morphology of the foot-rot fungus	103
Mycelium	105
Senescence phenomena of aerial mycelium	107
Conidiophores	109
Conidia	110
Etiology of foot-rot:	
Evidences of etiological relation of H. No. 1	124
Constant presence of the pathogene	124
Absence of other constant parasites	124
Identity of pathogene proved by culture	124
Evidence of infectiousness	124
Conidia produced in moist-chamber culture	125
Evidence from inoculation	125
Recovery of organism	128
Infection phenomena on wheat	128
Susceptibility of various hosts to infection	137
Summary concerning etiology of foot-rot	139

IV

II. Evidence and discussion of the occurrence of saltation within the genus <i>Helminthosporium</i> :	PAGE
Introductory	139
Characters of saltants as shown in transfers	141
Tendencies in saltation	145
Stability of the saltants	145
Stability of the saltants through the conidia	146
Apparent reversions	147
Supposititious causes of the variant sectors	147
Saltations from single conidia	149
Frequency of saltation	150
Saltations occurred on various media	152
Saltations and modifications occurring in test-tube cultures	152
Saltations in nature	154
Notes concerning selected individual saltants	155
General discussion of saltation	157
Taxonomy	164
Conclusion	168
Summary	168
Literature cited	171
Appendix:	
Methods	179
List of <i>Helminthosporiums</i> used for purposes of comparison	181
Discussion of foregoing list with several brief descriptions	184
Graphs: Figures A—Y.	
Plates: VII—XXXIV.	

ARTICLE V.—*The Helminthosporium Foot-rot of Wheat, with Observations on the Morphology of Helminthosporium and on the Occurrence of Saltation in the Genus.* By F. L. STEVENS.

INTRODUCTORY

The present study of wheat disease is based upon a foot-rot, or rot of the basal portion of the stems, of wheat plants, as it occurred in Madison county, Illinois, in 1919 and subsequently. This disease was first reported in United States Government publications as "take-all" (*Ophiobolus graminis*); later, merely as "take-all," no cause being assigned; and for some time past, in Government publications it has usually been designated as "so-called take-all." An annotated bibliography of nearly one hundred titles concerning foot-rot disease of wheat, prepared by the writer, was presented before the Cereal Pathologists of America at St. Louis in June, 1919, and this, expanded to one hundred and eighty-eight titles, was published in October, 1919 (116). As early as May, 1919, cultural studies quite clearly pointed to *Helminthosporium* as the true cause of the disease, and at the December meeting of the American Phytopathological Society I announced this fungus as the probable cause. In May, 1920, in a note in *Science* (117), I published the statement that it had been conclusively established that this foot-rot of wheat is caused by *Helminthosporium*.

One purpose of the present paper is to present the evidence on which the foregoing conclusion is based and certain facts concerning the morphology and parasitism of the fungus; but far transcending in interest the disease itself—which now appears to be one of much less alarming nature than was at first feared—is the fact that very striking phenomena of variability are found in this and related fungi. In the following pages, therefore, appear (I) an account of the Illinois foot-rot of wheat and its causal fungus; and (II) evidence and discussion of the occurrence of saltation within the genus *Helminthosporium*.

ACKNOWLEDGMENTS

In this study I have been assisted financially by grants from the Illinois Natural History Survey and from the University of Illinois. I am indebted for specimens to persons mentioned in the list of species used for comparison (pages 181-184), and to W. P. Snyder for computation of data embodied in several of the graphs. I wish also to express my thanks to Prof. J. A. Detlefsen, who kindly read the manuscript and offered valuable suggestions regarding genetic questions.

I. A Foot-rot of Wheat and its Causal Fungus

SYMPTOMS

As the name implies, the most obvious symptom is a rotting of the basal portion of the stem of the wheat plant, that is, the lowest portion of the lowest internode. In earlier stages than that of actual rotting, minute yellow or brown lesions occur on the stem (Pl. VII), while the roots, if diseased, are slightly yellowed and largely or quite devoid of functional root-hairs. No web of superficial mycelium or black incrustation, such as is so frequently described in articles concerning take-all, was seen. The diseased tissues, however, were invariably ramified by an internal mycelium. Certain cases of diseased wheat came under observation in which the plants had attained a nearly normal growth and were eighteen inches high, when they suddenly died throughout. In such cases there was a slight darkening of the lower node and a mycelial invasion at this point. The opinion of those who observed this wheat in the field was that the death was due to frost injury. It is probable that the actual cause of death was foot-rot following the frost injury.

FUNGI PRESENT

Direct microscopic observation of the diseased tissues, in all cases of foot-rot examined, revealed the presence of an internal hyaline or faintly tinted mycelium in great abundance permeating the diseased tissues. Mycelium of different character was also occasionally found, but so inconstantly as apparently to have no actual relation to the disease. Isolations of the fungi present in the diseased tissues were made by two methods:

1. Direct planting of bits of diseased tissue on poured agar (corn-meal agar or wheat-straw agar). The diseased tissue was secured in as clean condition as possible by stripping back the enclosing sheaths, excising the diseased part with sterile tools, and tearing it apart in a sterile Petri-dish.

2. Direct planting of similar bits of diseased tissue after surface-sterilization in mercuric chloride (1-1000, 10 min.).

Dilution plating was unsatisfactory owing to the paucity of conidia and the presence of numerous soil bacteria, particularly "spreaders."

As might be expected, the methods employed gave rise to colonies of many genera and species, including *Phyllosticta*, *Septoria*, *Fusarium*, *Epicoccum*, *Alternaria*, and *Helminthosporium*. A striking fact, however,

was that with the exception of the *Helminthosporium*, these fungi were very rarely present, and then only a single colony or part of a mixed colony on occasional plates. *Alternaria* occurred with remarkable rarity; only two or three colonies among several thousand. *Fusarium* was found in only a few colonies and so mixed that it was isolated with difficulty. *Epicoecum* occurred in two colonies; *Phyllosticta* also in two colonies (two species).

A *Helminthosporium*, however, appeared in every plate and from nearly every bit of tissue used, no matter how great the care in securing the inoculum. On many plates this *Helminthosporium* (which throughout this article I designate as H. No. 1) appeared in pure culture. Thus it may be said that the *Helminthosporium* was universally present in the plates; that it was the only organism that was present with any constancy; and that all other fungi were obviously strays.* Though conidia were never found in great numbers on plants brought in direct from infested fields, when the plants were placed in moist chamber for two or three days conidia developed in abundance. This was also the case with portions of wheat stems which had been placed in bichloride of mercury for ten minutes and then placed in moist chamber for several days. In passing it may be remarked that although great numbers of nematodes and amebae appeared in the plates there is no reason to believe that they had any relation to the disease under discussion or to any diseased condition.

GROWTH OF THE CAUSAL FUNGUS ON VARIOUS MEDIA

Since the characters exhibited by various *Helminthosporiums* when growing in artificial culture have been considered as of importance as a means of distinguishing one species, variety, race, or strain from another, many media were employed in the present study. This was done in part for the purpose of comparing the growth characters of the *Helminthosporium* with characters reported by others in connection with other forms; in part with the hope that some of the media tested might give emphasis to certain characters and thus serve to differentiate between species or strains of the forms under observation.

The following notes are, in the main, statements of the characters presented by the foot-rot *Helminthosporium* (H. No. 1), though for the purpose of comparison notes are added regarding the growth of several

*A letter from Professor Hoffer written in May, 1919, tells me of a similar result from platings of wheat foot-rot from Indiana, and similar reports reach me from several other sources.

species or strains of *Helminthosporium*. These are throughout referred to by number rather than by name, partly for brevity and partly because the species of many of the races had not been determined, while in some cases the names were of more or less doubtful reliability. That the reader may formulate his own judgment of these forms, introduced for comparison, a complete list of them is given in the appendix (pages 181-184) together with certain notes regarding them.

VARIOUS AGARS AS MEDIA

Corn-meal agar in Petri dishes.—This medium, prepared after the directions given by Shear and Stevens (104), was found to be admirably suited to *Helminthosporium* and was the medium chiefly used.

The fungus grew rapidly, the colony being at first nearly hyaline both in the submerged and aerial parts, but when a diameter of about 2-3 cm. was attained the whole colony became much darker. Profusion of conidia was the chief factor in giving the dark hue to a colony, the slight darkening of the mycelium having little to do with it. The aerial mycelium varied largely with change of conditions, sometimes being very scant and at other times 5-6 mm. high, with windrow effects corresponding with the zones. After the colony was about 3 cm. in diameter zonation became quite pronounced, the zones corresponding approximately with the growth of each day. At room-temperature the colony attained a diameter of about 4.5 cm. in six days. Conidia-production was quite uniform over the surface of the colony unless checked by some growth-inhibiting cause, as drying, cold, or the antagonism of another colony near by, when it was much increased, as evidenced to the eye by black bands in such regions. By transmitted light the mycelium, and to some extent the conidia at certain ages, had a distinctly greenish tinge. H. No. 1 could be distinguished from H. Nos. 5-8, which were paler and produced fewer conidia. H. No. 6 approached nearer to H. No. 1 in these regards than did the others. H. Nos. 3, 4 (see Pl. IX), 6, 15-17, and 18 typically developed more aerial white mycelium than did H. Nos. 1 and 14. H. No. 36 was of very distinct character owing to large development of aerial mycelium (see Pl. X).

Corn-meal agar in Freudenberg flasks.—The flasks, of about 100 c.c. capacity, each received 50 c.c. of agar and were slanted. The large amount of nutriment available and the sustained moisture gave noteworthy characters. At 7 days, with H. No. 1, the surface of the slant was com-

pletely overgrown and of an even black color, largely curtained by an abundant, even overgrowth of white aerial mycelium. At contact with the glass a sharp, black line gave clear evidence of the black surface-coat. No clumps or balls of mycelium were present. At 22 days a few clumps developed, though not so many as on H. Nos. 9, 13-16.

Cultures of H. No. 1 on corn-meal agar in large flasks, as those of Kolle or of Piorkowski (Pl. XI-XIII) gave colonies very different from those on the ordinary Petri dish, due presumably to the larger quantity of nutrient available and to different humidity relations. These flasks gave increased density of colony and conidia-formation, more aerial mycelium, and some clumping of the mycelium. Though colonies of H. No. 3 and H. No. 1 differed in these characters in these flasks (Pl. XII, XIII), portions of the colonies of these strains were indistinguishable.

Corn-meal agar made at various temperatures.—Corn-meal agar was made in the usual manner excepting that the temperature in three cases was held at 43°, 85°, and 100° respectively, instead of at 60°, before filtering. Duplicate plates were made. The four resulting agars are designated according to the temperatures held, and colony data for each are presented in the following table.

CORN-MEAL AGAR MADE AT VARIOUS TEMPERATURES

Temperature	Growth in 8 days	Zonation	Density	Colors
43° 43°	7.5 7.2	distinct	thin	pale
60° 60°	5.5 6			
85°	6.5	In above characters, ranks between 43° and 60° agars		
100° 100°	8 7.8	none	very thin	very pale

The 100° agar is most favorable to linear growth, 43° agar stands next; 43° and 85° agars give growth of poorer color than 60° agar, but 100° agar ranks lowest in this regard. Color is directly due to quantity of conidia, and it is uniform in the mycelium on the four agars. Nutrition in 100° agar was very little better than in plain agar. In general, it

appears that their order of nutritive value for this fungus, from poorest to best, is 100°, 43°, 85°, 60°. Evidently a temperature of 43° is insufficient to extract the nutrient proteids sufficiently, while 100° precipitates too many of them. While leucosin, a prominent proteid of the embryo, is largely precipitated at 52° and a second coagulum goes down at 82°, no more is precipitated even by boiling (Osborne, 89).

Graphs 1-4 (Fig. A), indicating conidial length on these four agars, show that although the quantity of conidia produced varied materially, the length and general variability are not greatly influenced by varying the composition of the agar—done in this case by change of temperature. The conidial length of all these agars is, however, considerably less than that on wheat shoots (cf. graphs in Fig. A and Fig. K). Graphs of conidial breadth and septation on 43° and 60° agars given in Fig. B also show but little influence of these agars on these two characters. A "Difco" corn-meal agar, prepared according to my directions by the Digestive Ferments Company, gave growth-characters almost identical with those of my own 60° agar. On "Difco" beef-agar the conidia were short, and were frequently deformed ($M, 17.44 \pm .22$, $\sigma, 2.46 \pm .16$, $CV, 14.15 \pm .93$).

Plain agar (shredded agar only, 12 g. per liter).—The fungus grew rapidly, and in 6 days the colony was 35–45 mm. in diameter, but was thin and colorless, with but few scattered conidia, and only 1 to 3, or at the most 7 to 10, conidiophores per low-power field, except at growth-inhibition points, as at the edge of the dish or where two colonies approached each other, where the number of conidiophores rose to about 12 per low-power field. The conidiophores bore only one or two conidia each. Conidiophores, conidia, and mycelium as well, were very faintly straw-colored, much paler than on more nutrient agar. No zonation occurred. No difference in rate or character of growth was observable in 1.3% and 2.6% plain agar.

Growth on plain agar, on corn-meal agars, and on various combinations of these nutrients.—Corn-meal agar of various compositions was used, 12 c.c. to each Petri dish. On 25% corn-meal agar (made of 3 parts plain agar plus 1 part ordinary corn-meal agar) the colony was much darker and denser than on plain agar; was zoned more strongly; and conidia were much more abundant, there being about 80 conidiophores per low-power field, each with one to five conidia. The mycelium was much darker than on plain agar. Colonies on 50% and 75% corn-meal agar showed no essential difference from the colony on 25% agar. On full corn-meal

agar the colony was much darker and more dense and the mycelium was darker. The relative rate of linear growth on these agars, as shown in millimeters of colony diameter at the end of 9 days at room-temperature, was as follows:

On plain agar.....	70 mm.
On 25% corn-meal agar..	68 mm.
On 50% corn-meal agar..	62 mm.
On 75% corn-meal agar..	57 mm.
On 100% corn-meal agar..	54 mm.

When the fungus was planted on plain agar, and pieces (1 cm. square) of corn-meal agar of the above-mentioned compositions were laid on the surface at the edge of a well-developed colony, both color and conidia-production increased with the increase of nutrients. Variation in conidial length on these agars is shown in Fig. C. On this series of agars conidial length was least on plain agar and increased consistently with the strength of the medium. It is to be noted that the coefficient of variability is very high on the 75% corn-meal agar. In Graphs 9 and 10 of this Fig. C, conidial length is seen to be appreciably lower than on full corn-meal agar (Graphs 1-4, Fig. A), and markedly shorter than conidia grown under standard conditions (see Graphs, Fig. K; also App., page 180). Again, corn-meal agar was made in the usual way but the amount of agar was varied, 6, 12, and 25 grams per liter being used. In general, in Petri dishes, 12 grams per liter proved most suitable. Comparisons between H. No. 1 and H. No. 3 on these three media showed at 11 days each that H. No. 3 had grown more rapidly than H. No. 1, the ratio being 6.8: 8.5. There was usually a marked difference between these two strains on 12-gram corn-meal agar, more marked than on the others, H. No. 3 showing more definite zonation and more aerial mycelium.

In Freudenreich flasks, with the 6-gram agar, H. No. 3 made much aerial mycelium on the watery surface; H. No. 1 made only a black pellicle and no aerial mycelium. On 12-gram agar H. No. 1 made small growth of aerial mycelium and the colony surface was black, while H. No. 3 had much loose, woolly mycelium. At 11 days H. No. 3 on each agar had more aerial mycelium and more clumps than did H. No. 1. The most conspicuous difference was on 12-gram agar, while on 25-gram agar H. No. 1 had no clumps and H. No. 3 a few.

There is a clear, definite tendency in H. No. 3 to make more aerial mycelium and more clumps than H. No. 1, but this is so dependent on con-

ditions of moisture, in air and medium, that it is far from being a reliable character for separating the two.

Green-wheat agar.—(Formula as for corn-meal agar, substituting for the corn-meal live wheat leaves and stems which had been passed through a meat-grinder.) H. No. 1 grew well, producing a dense colony, but with weak zonation and with much woolly, white aerial mycelium, and but few and scattered conidia. This medium, while apparently very nutritious, favored abundant vegetation rather than sporulation, and was a poor medium for the differentiation of races.

To determine the effect of reducing the nutrients in green-wheat agar, this was combined, in varying proportions, with washed agar with varying results. On washed agar the growth of H. No. 1 was scant, colorless, and with no conidia, the colony diameter reaching only 5.5 cm. in 9 days. As the content of green wheat was increased, there was a gradual increase in density of colony and of aerial mycelium. In 9 days the colony diameters were as follows:

On 25% green-wheat agar. .9 cm.
 On 50% green-wheat agar. .8 cm.
 On 75% green-wheat agar. .7.5 cm.
 On 100% green-wheat agar. .7.5 cm.

These colonies showed no dark color and only very weak zonation, and in the two high concentrations the aerial mycelium developed into a dense, closely felted mat. Conidia were produced scantily and varied greatly from the shape found elsewhere, being less tapering, more nearly cylindrical, and materially thicker (Graphs 13, 14, Fig. D). In some instances septation differed markedly—diminished (Graphs 15, 16, Fig. D). Many large conidia had no septa at all, and others had irregular or incomplete septa. It is evident that this medium, even at 25% strength, induces many abnormalities, and the very high coefficient of variability is especially striking. The differences in septation here noted were not constant on the same plate and were much more common at the drying edge. On this agar conidial length was less than under standard conditions (see appendix, p. 180).

Wheat-straw agar.—(Fifty grams of old wheat-straw, boiled 20 minutes and filtered.) Growth was poor.

"Disco" beef-agar.—H. No. 1 grew slowly but was very dense; surface even; little aerial mycelium.

Starch agar.—This medium proved to be of but slight differential value. The growth was of a dark color and of somewhat bluish tinge.

Bean agar.—H. Nos. 1, 3, 5, 13, 20, grew well on bean agar, all developing a dense, woolly, gray aerial mycelium. Zonation was poor, or obscured by the aerial mycelium. The five strains showed no differences in growth on this medium, which was therefore poor for differential use. In Freudenreich flasks there was a definite black surface-line and much tawny aerial mycelium in clumps.

Brazil-nut agar.—(Formula according to Spencer, 108.) H. No. 1 in test-tubes grew very rapidly and luxuriantly with small development of aerial mycelium and a distinct black basal line. The agar was rapidly cleared of proteid precipitate by the development of a proteolytic enzyme. In Petri dishes a thick, dense, woolly, snow-white aerial mycelium developed which entirely curtailed the surface-blackening. The colony was surrounded by a broad translucent zone due to proteolytic action. This agar is valuable for the pure-white aerial mycelium that develops on it, and to demonstrate readily the proteolytic action, though it did not, even in these regards, prove to be differential, since all of fifteen strains tested upon it gave nearly identical responses.

Oat agar.—H. No. 1 at 10 days gave a distinct black surface-line and very heavy aerial gray growth. H. Nos. 1, 4, and 14 were indistinguishable on it.

Apple-fruit agar.—H. No. 1 gave a black basal line and abundant, sooty aerial mycelium. H. Nos. 1, 4, and 14 were alike except that No. 4 produced large sclerotia.

Apple-bark agar.—H. Nos. 1, 4, and 14 grew very slowly and were very dense and black, with but little aerial mycelium.

Czapec agar.—H. No. 1 gave a black surface-line and no aerial mycelium. H. Nos. 4 and 14 were of the same character except that No. 4 produced a considerable quantity of smoky aerial mycelium.

Prune agar.—H. Nos. 1 and 4 gave a dense, black surface-growth but no aerial mycelium.

SUMMARY CONCERNING GROWTH ON AGARS

Corn-meal agar made by the usual 60° formula proved most useful, and the best differential agar. If made at 100° or at 43° it lacked nutriment. The amount of agar used—even 25 g. per 1000 c.c.—had but little effect on growth characters. Green-wheat agar in varying strengths led to luxuriant vegetation, to little conidia-production, to much abnormality

in morphological characters, and was of little differential value. On either washed agar or plain agar there was excellent linear growth but poor color and little conidia-production. Bean agar gave too luxuriant vegetative growth. Brazil-nut agar was useful for the development of white mycelium for use in nutrition studies and for study of proteolytic action. The other agars used showed no special features of value.

RICE AND SIMILAR SUBSTANCES AS MEDIA, WITH SPECIAL
NOTE OF COLOR PHENOMENA

Rice in test-tubes.—Rice was prepared in the customary way, by placing it in test-tubes to a depth of one centimeter, adding enough water to stand 1 cm. above it, and then autoclaving. This medium, so useful in the study of many fungi, notably of *Fusarium*, proved very interesting here. At the expiration of about two weeks from the time of inoculation—generally the most profitable time for first observation—three zones or regions could usually be recognized: (1) the region recently invaded by the fungus, which I designate as the *recent* region; (2) the region first invaded, which had assumed nearly its final appearance, and which I call the *old* region; and (3) the region midway between 1 and 2, which I shall call the *median* region.

Each of these regions showed characters of its own. Within all of them, but particularly in the old and in the median regions, there were three points to observe: (*a*) the places where the rice grains came in contact with the glass, which places I call *contact*; (*b*) the spaces between rice grains, at first filled by water, which I call the *interstices*; and (*c*) the line between interstices and contacts, which I term the *border*. Usually the fungus grows down into the interstices, consumes their contents, and fills the remaining space more or less completely with mycelium. Penetration of the contacts is very slow and may not occur at all, therefore they are usually but slowly discolored by the passage of various chemicals into them. The border is the region of greatest development, and often presents a sharp, distinct line of pronounced character. It is the contrasts furnished by the contacts, interstices, and borders, often attended by the development of beautiful and vivid colors, that give to these cultures their striking appearance. In addition to these characters the final appearance of the rice column should be noted. It is sometimes digested away in characteristic manner. The development or absence of sclerotia is also noteworthy.

H. No. 1, in rice test-tubes, at two weeks, gave, in the recent region, salmon-colored interstices, contacts, and borders; in the median regions the

interstices and contacts were gray, the borders olive; in the old regions the interstices were dark, contacts gray, and borders deep black. No sclerotia developed.

H. No. 2 gave quite distinctive color-characters, as did also Nos. 11, 12, 16, 17, and 19, including the colors pink, brown, red, gray, and purple. The remaining strains were distinguished only by sclerotial development, in which character strains known to be closely related differed markedly.

Additional notes made on these cultures at later periods, up to four weeks, differed only as to sclerotial development and the wasting away of the rice column. At four weeks H. No. 1 produced some sclerotia, and at five weeks, many.

In an attempt to ascertain wherein lay the responsibility for the various colors found in rice cultures, tubes were made in the usual way, using rice chaff, whole rice, rice from the pearling cone, rice from the brush, and rice polish. Of these, rice chaff and whole rice gave no color reactions; but all the others gave the usual ones. Single grains of autoclaved rice were placed on washed agar, under a cover-glass, and inoculated with color-producing *Helminthosporiums*. Direct microscopic observation showed the most intense colors on the unbroken rice-surface, and less intense ones on interior regions exposed by breaking. It is therefore probable that the proteids, which are most abundant in the surface layers, are necessary to the color responses, though the color itself often, if not always, arises from the mycelium.

Pearl-barley (prepared like rice tubes).—The general character of the growth as to contacts, interstices, and borders was as on rice but with different and less pronounced coloring. H. No. 1 at two weeks gave, in the recent region, salmon interstices, contacts, and borders; in the median region, gray interstices and contacts and olive borders; in old regions, dark interstices, gray contacts, and black borders; and the aerial mycelium was gray and the barley column not shrunk.

Navy beans (prepared like rice tubes).—H. No. 1 grown on this medium two weeks gave contacts unchanged, interstices gray to brown, borders brown to black. Little of differential value developed, though H. Nos. 11 and 19 gave pink colors.

Wheat grains (prepared as above).—H. No. 1 in old region gave contacts unchanged, interstices dark gray, borders black, and a very few sclerotia developed. H. No. 3 gave the same characters but more numerous sclerotia.

Almond integuments (prepared as above).—H. No. 1 gave a dense, black mycelium and abundant conidia.

Corn meal (moistened and autoclaved in test-tubes).—H. No. 1 gave dense, black borders and greenish-black interstices.

Corn-starch (prepared as above).—H. No. 1 gave a dense, black, even surface-growth with little or no aerial mycelium.

SUMMARY CONCERNING GROWTH ON RICE AND SIMILAR SUBSTANCES

With *Helminthosporium*, as with *Fusarium*, rice tubes are of value for differentiating species. The important constituent seems to be in the aleurone layer. Pearl-barley has similar and different, though less, value. Whole wheat grains, whole rice, beans, etc., do not give these color reactions.

Color phenomena in fungi have been discussed by Smith (106), and Hedgecock (65), and by Stewart and Hodgkiss (119), who cite several papers bearing upon the subject. These, however, deal mainly with conditions of acidity and general carbohydrates rather than with proteid relations.*

MISCELLANEOUS VEGETABLE MEDIA

Parts (plugs) of various vegetables were placed in test-tubes—in some cases with glass slips—with about 2 c.c. of water and autoclaved. The chief resulting characters of various *Helminthosporium* plantings on such media consisted in the development of aerial mycelium and the pellicle over the surface of the water.

Potato plugs (prepared in the usual way).—H. No. 1 gave on these plugs large development of woolly, white aerial mycelium. At the line of contact with the glass the growth was dense and black. No sclerotia developed in four days. This medium possessed little differential value, only H. Nos. 11, 12, and 17 showing clear differences.

Potato plugs on glass slips.—The slips were placed in test-tubes (in the manner shown in Fig. 2, page 95), and then slices of potato, which were so cut that they could barely be crowded into the tubes. They were then autoclaved. This gave opportunity for observation at three places: (1) the exposed potato surface; (2) the contact of the potato with the glass slip and with the wall of the tube; and (3) the border at the edge of the contact (cf. with terms under rice, p. 86). H. No. 1 here gave a dense black

*In this connection see paragraph on carbohydrates on page 100.

border, a woolly, smoky aerial surface, and was black at contacts. H. Nos. 11, 12, and 17 were otherwise colored.

Carrot plugs on glass slips (manipulated as above).—H. No. 1 gave black border and scant aerial mycelium; H. Nos. 11 and 17 were quite different.

On other carrot plugs, placed in test-tubes but without the glass slips, H. No. 1 gave at 4 days a slowly developing black surface-growth. H. No. 3 grew faster and with more aerial mycelium. At 9 days, H. Nos. 1 and 3 were alike.

Sweet-potato plugs.—H. No. 1 at 4 days was densely woolly on the surface; surface of H. No. 3, less woolly. At 9 days H. Nos. 1 and 3 were alike.

Onion bulbs; radish root.—H. No. 1 and H. No. 3 had abundant mycelium, a pellicle, and conidia.

Celery, onion stems, green peas, pea-pods, string-beans.—H. Nos. 1 and 3 had made dense, white, woolly aerial mycelium.

Rhubarb stems.—H. No. 1 made no growth; H. No. 3, poor growth.

Cranberries.—H. Nos. 1 and 3 made no growth.

Bean broth.—H. Nos. 1 and 3 gave a thick pellicle and a scant aerial mycelium. This medium has little differential value, though large white mycelial clumps appeared in H. Nos. 7, 8, and 9, much less in No. 6, and in some cases there was no pellicle. These characters, however, appear too variable to have value.

Old wheat-straw.—Old, dry wheat-straw, cut free of leaves and into lengths of about 12 cm., was placed in test-tubes with a few c.c. of water and autoclaved. Inoculated on these straws, H. No. 1 grew well, largely covering the lower part of the stem (which was in the most humid air) with a black coating of conidia. Each conidiophore usually produced several conidia. On the upper part of the stem, which was in less humid air, conidia were produced much less abundantly and were usually solitary on the conidiophore, while on the portion of the stem very near the cotton plug there was a growth of aerial mycelium. The fungus also grew sparsely over the surface of the water, where it produced conidia. Nineteen other numbers of *Helminthosporium* were grown on this medium and kept under observation more than three months. Three numbers, 11, 17, and 21, showed distinctive characters, and among the others there were minor differences in conidia production, in amount of aerial mycelium on the upper end of the straw, and in the density of the pellicle. These differences were, however, as great between two cultures known to be

of the same species (e. g., H. Nos. 5 and 6), and between H. No. 20 and No. 13, presumably of the same species, and therefore they are not of reliable taxonomic value. Even at the end of three months there were no sclerotia, pycnidia, or perithecia in any of the tubes. Ravn (91) has stressed the importance of sclerotia (which this medium yielded in his studies) as a means of distinguishing certain races or species; but no such value attaches to it for the races that I had under observation.

Fresh wheat-leaves.—Green wheat-leaves were prepared in the same manner as the wheat straw. On these leaves growth of H. No. 1 was much as on the wheat straw except that many more conidia were produced both on the lower portions of the leaf and on the water-surface. On the upper part of the leaf, about 6 cm. above the level of the water, where the leaf was too dry for conidia-formation, a rather extensive, white, floccose, loose aerial mycelium developed.

SUMMARY CONCERNING THE FOREGOING VEGETABLE MEDIA

But little of differential value resulted. The characters of aerial mycelium, sclerotia, clumping of mycelium, and pellicle-formation were but slightly marked, all being highly dependent on conditions of environment.

CEREAL SHOOTS GROWN FROM ASEPTIC SEEDS AS MEDIA

Cereal seeds were disinfected and sprouted in sterile moist chambers. When the shoots were 2-3 cm. long they were cut off, placed in water in a test-tube, and autoclaved. Next, washed agar was placed in Petri dishes and inoculated with H. No. 1. About four days later, when the colonies were several centimeters in diameter, various cereal shoots, prepared as above, were laid on the washed-agar plates, the basal end of the shoot in each case touching the edge of the colony. In this way repeated tests were made with wheat, oats, corn, rye, and barley, with the invariable result that growth was most luxuriant and dense on the corn, which soon became completely black. No constant difference was evident between the other cereals, except that rye seemed a medium slightly less favorable than the others.

It seemed probable that the more luxuriant growth and conidia-development on the corn shoots was due to quantity rather than to quality of nutrients. To test this hypothesis an entire corn shoot, a longitudinal half of a shoot, a longitudinal quarter of a shoot, and a mere longitudinal filament were laid on a colony of H. No. 1 growing on washed agar. On the smallest fragment, growth and conidia-production were about as on

wheat. The quantity of conidia produced, and correspondingly the black color, bore a direct relation to the mass of the corn shoot. It is probable that all of these autoclaved shoots are of equal, or nearly equal, nutritive value for a given amount of material.

Eleven other strains of *Helminthosporium* were tested in similar manner, using wheat, oat, and barley shoots. No significant differences in growth appeared, though, in most cases, at the end of the growth-period there was a somewhat more profuse development of conidia on wheat than on the two other cereals.

ENVIRONMENTAL FACTORS WHICH INDUCE VARIATION

Since classification of these fungi is necessarily based primarily on morphology, and on growth characters as exhibited on various media, it is important to know what, and how great, variations in these characters are induced by environmental changes. It is generally conceded that culture characters to be comparable must be noted under similar conditions. But how much latitude is permissible here; what difference in environment may be regarded as negligible? Fungi are collected that have grown under different conditions of nutrition, humidity, temperature, etc., and specific descriptions are written, based on these collections. To what extent are they trustworthy? The size and shape of the conidia and septation are regarded as of the highest taxonomic value. The development of sclerotia, of aerial mycelium, of mycelial clumps, of color, etc., are often the only characters separating some types regarded as species. Even the characters of the colony on the agar plate are considered important. It is with the hope of throwing some light upon this phase of the subject that I record the following additional observations concerning environmental factors which induce variation. More complete and exhaustive studies on these and kindred phenomena are needed.

QUANTITY OF NUTRIMENT

Petri dishes were respectively supplied with 12 c.c. and 30 c.c. of 60° corn-meal agar and inoculated with H. No. 1. Placed under the same conditions, these dishes gave very different colony-characters. The colonies on the plates containing the larger amount of agar were very dense and black, and covered the agar-surface much more completely than did the colonies on the plates containing less agar (Pl. XIV). There was also marked difference in the rate of linear growth, as is shown in the following table:

GROWTH IN DIAMETER OF COLONIES (MILLIMETERS)

<i>At 4 days' age</i>		<i>At 11 days' age</i>	
On 12 c.c. of agar	30 c.c. of agar	On 12 c.c. of agar	30 c.c. of agar
pl. 1, 22	pl. 8, 32	pl. 1, 60	pl. 8, 85
pl. 2, 25	pl. 9, 40	pl. 2, 65	pl. 9, 90
pl. 3, 29	pl. 10, 32	pl. 3, 65	pl. 10, 85
pl. 4, 32	pl. 11, 40	pl. 4, 63	pl. 11, 85
pl. 5, 25	pl. 12, 35	pl. 5, 63	
pl. 6, 29		pl. 6, 62	
pl. 7, 27		pl. 7, 65	
—	—	—	—
Totals, 189	Totals, 179	Totals, 443	Totals, 345
Av. per pl.,	Av. per pl.,	Av. per pl.,	Av. per pl.,
27 mm.	35.8 mm.	63.3 mm.	86.2 mm.

It appears that at 4 days the colonies on the deep agar grew more than 32% faster than those on the plates with less agar; at 11 days, more than 28% faster, the colonies being at the same time more dense. A repetition of the test with 16 plates gave at 9 days a growth-average of 50 mm. on the shallow agar and of 74 mm. on the deep agar—an increase of 48% in rate.

Since it was deemed possible that the differences here noted might be due to differences in humidity, the depths of several plates were carefully measured and sufficient agar poured into each to make the air-space above the agar in all cases equal, although, since half of the plates were shallow and half of them deep, there was a great difference in the depth of agar used, which averaged in the deep plates about 11 mm. and in the shallow plates about 3 mm. The results of this test were almost identical with those recorded above. The differences noted, therefore, could hardly have been due to differences in humidity, but rather to the amount of nutriment available. The graphs of conidial length given in Fig. E show a larger predominance of short conidia on the deep agar, indicating the continuance of conidia-formation for a longer period of time. For this reason the mean length is much lowered and the coefficient of variability on the deeper agars is much higher than on the plates with less agar.

These results on deep agar are in entire agreement with those already given concerning corn shoots (page 90), to the effect that quantity of nutriment available may influence the growth-characters very markedly, often as distinctly as does the quality of the food available. The dilution experiments with green-wheat agar and corn-meal agar (pages 83 and 84) tend toward the same conclusion, though other factors also appear in those cases.

INHIBITORY INFLUENCES

Many influences which inhibit or retard vegetative growth, in so doing call forth increased sporulation, in accordance with the second law of Klebs (74) that the conditions favoring sporulation are always more or less unfavorable for growth. Thus, two colonies of H. No. 1 on washed agar were independently nearly devoid of conidia; but when they grew and approached each other, vegetative growth was retarded, and eventually inhibited, and each colony became dark in the region of inhibition, owing to much-increased sporulation (Fig. 1). Colonies of many other species of fungi affected H. No. 1 similarly under like circumstances, as did also drying out of the agar at the colony's edge. Similar changes in growth, and consequently in colony-character, occur on almost any medium, prominently on corn-meal agar, and they must be understood and reckoned with if colony characters are to be used for descriptive purposes.

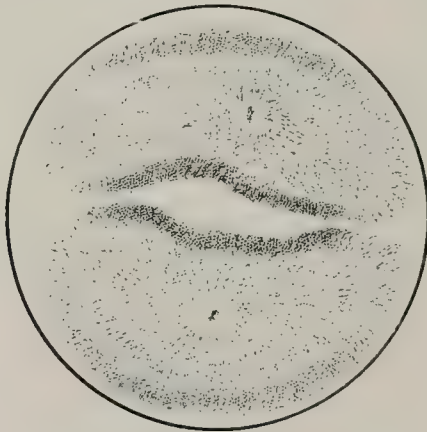


Fig. 1—Illustrating inhibitory influence on sporulation. Two colonies of H. No. 1, on washed agar, showing dark bands, due to abundant sporulation where the colonies approach each other. Sporulation also somewhat increased near margins of colonies, owing to drying.

HUMIDITY OF MEDIA

Rice was placed in tubes with water equal to twice the volume of the rice, and with water equal to four times its volume, being then autoclaved and inoculated with various *Helminthosporiums*. Notes at two weeks show better characters of border, interstices, etc., in the wetter tubes, and while with many strains sclerotia developed abundantly in the drier tubes

they did not appear at all in the wetter ones (Pl. XV). This was notably true of H. Nos. 1 and 5. Even at the end of five weeks no sclerotia were produced in the wet tube by H. No. 1. It is apparent that the smaller amount of water is the more favorable for observation of sclerotium-formation, either at two or four weeks, and that observation of wet tubes at the end of two weeks is sufficient for other characters. Ravn (91) has suggested sclerotial formation as a character for the separation of certain species. It is obvious that if this character is employed care must be given to the humidity of the media.

HUMIDITY OF AIR

Test-tubes were prepared with water in the bottom and a glass slip inserted as is shown in Fig. 2, and autoclaved. If filter-paper or a wheat leaf is laid on the glass slip the humidity is sustained throughout the length of the tube by evaporation from the leaf or the paper, but if no such conductor of water is used, and cereal (e.g. wheat) shoots are laid crosswise on the glass slip (as indicated in Fig. 2) and inoculated, the growth of the fungus may be observed under different conditions of air-humidity.

Determinations kindly made for me by Dr. G. L. Peltier with especially accurate apparatus devised by Dr. C. F. Hottes, showed that moist wheat sprouts became shriveled and apparently dry in 3 hours at a relative humidity of 0 to 60%; in 12 hours, at 70% and 80%; in 24 hours at 90%, and that only in a relative humidity greater than 90% did the sprouts remain apparently moist for a longer time.

Test 1. Moist sterile wheat-shoots were placed on the glass slip (as shown in Fig. 2) with centimeter intervals between them, and inoculated with *Helminthosporium* No. 1. All shoots 3 cm. above the water-level dried within 24 hours, indicating that a relative humidity as high as 90% existed only in the region of the lowest shoot and that next above it. In the region of approximately 90% relative humidity many of the conidiophores became abnormally long (600 μ), and the basal part was of mycelial rather than of conidiophore character (cf. Fig. 3). It was apparent from observations on shoots in these various humidities that when the air was too dry for conidia-production there was a considerable development of aerial mycelium, which accounts for the fact that frequently the basal portion of a vegetable stem (e. g., celery or wheat) may bear conidia, while the upper part bears a tuft of woolly aerial mycelium.

Test 2. Old, dry wheat-straw with water in test-tubes was autoclaved and inoculated with H. No. 1. In the humid bottom the conidia-clusters

were large, as was also each conidium. Toward the dry end the conidia-clusters and the conidia both became smaller. From graphs of conidial length (Fig. F) it is obvious that the mean length of the conidium is much

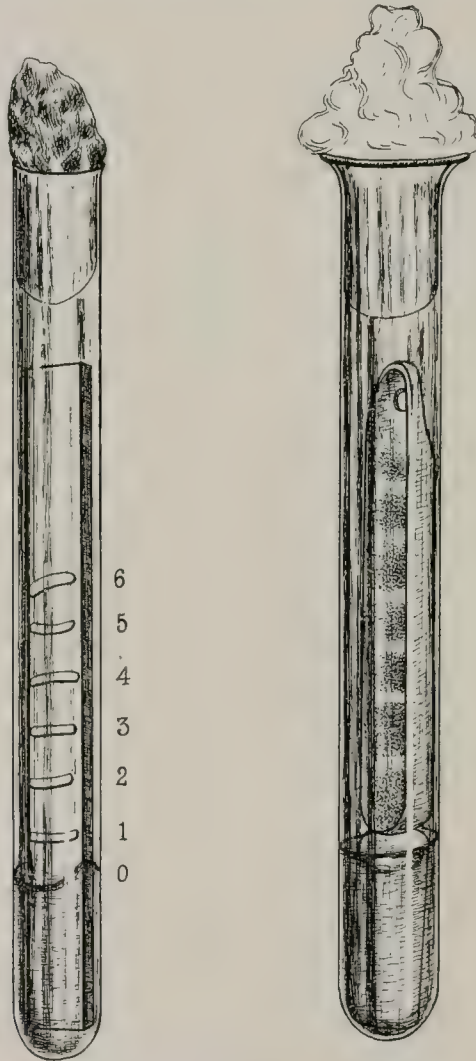


FIG. 2.—Showing at left, glass slip in test-tube: 0=water level, 1, 2, 3, etc., position of wheat shoots. In other test-tube, combustion boat supported on a bit of glass tubing, colonies growing on the agar in the boat.



FIG. 3.—H. No. 21, showing origin of conidiophores from mycelium under humid conditions, the conidiophores being very short, thick, crooked, and black.

reduced by an environment of relatively dry air; also that the relative variability is much increased by these conditions (cf. data of Fig. F with data of Fig. A and Fig. G). The great influence of humidity on the morphology of conidia and conidiophores is discussed by Wartenweiler (124). Pammel, King, and Bakke show by respective illustrations (90, Pl. I, figs. 1, 2, 3, and 13-16) large variation in shape and size, and apparently in mode, of conidia of *Helminthosporium* as grown in the field and in the greenhouse. Similar effects from humidity were noted by Beach (12) in *Septoria*. The relative paucity of sporulation and the tendency of *H. No. 1* to turn to the production of aerial mycelium unless the air-humidity was very high, and to proceed to profuse conidia-formation only when the relative humidity was above 90%, explains the failure to find *Helminthosporium* conidia on diseased wheat-stems in ordinary moist-chamber conditions, though these same stems, when given very moist conditions, invariably became covered with *Helminthosporium* conidia.

The six strains of *Helminthosporium* subjected to the humidity tests all agreed in essential behavior and characters with the reaction of *H. No. 1* to the same, as given above; but there is apparent disagreement here with the conclusions of Ravn (91) who says that he placed "no water in the damp room (Boettcher chamber) since the moisture would be so great that it would prevent the development of conidia."

Test 3. Under a bell jar lined with filter-paper dipping in water—thus securing a close approximation to a saturated atmosphere—open Petri-dishes of inoculated corn-meal agar were placed. Under these conditions *H. No. 3* made much more white aerial mycelium than did *H. No. 1*, and also grew faster, whether on thin (30 c.c.) or thick (60 c.c.) layers of agar.

It here appears that a condition of excessive humidity best develops the differential characters of the aerial mycelium of these closely related races.

Test 4. *H. No. 1* was grown on corn-meal agar, and when the colony was well developed it was dried slowly until growth completely stopped. This resulted in a dense black band of conidia near the edge of the colony. There were many conidia upon each conidiophore, as many as thirteen being counted in one instance, and the conidia clusters resembled bunches of grapes. Only the oldest conidia of a cluster were at all large and these fell far below the mean as grown under standard conditions, while the other conidia were much below the usual size (cf. Graphs 62-64 [Fig. O] and 39-42 [Fig. K]) and extremely variable, with coefficient of variability 29.99 as compared with 12.22 under standard conditions (Graph 42, Fig. K). It

is obvious that such drying as is here recorded results in increase in the number of conidia per conidiophore; in great reduction in the modal mean and length; in increase in variability; and even in bimodality of length-graph. A count of scars per conidiophore gives the following: 1 case with 4 scars; 1 with 5; 3 cases with 6 scars; 3 with 7; 2 with 8; 2 with 9; and 1 case with 10. This record affords a marked contrast with the more usual condition of only 1, 2, or 3 conidia per conidiophore.

TEMPERATURE RELATIONS

The following is the record of *H. No. 1* on 10°, 15°, 25°, and 30° washed agar at 87 hours: at 10°, trace of growth; at 15°, colony 10 mm. in diameter; at 25°, 21 mm. in diameter, at 30°, 19 mm.

GROWTH OF *H. NO. 1* ON CORN-MEAL AGAR

Temperature	Dish No.	Growth of colony-diameter (millimeters) at time-periods indicated									
		2 da.	3 da.	4 da.	5 da.	6 da.	7 da.	9 da.	13 da.	17 da.	20 da.
10°	1	4	11	15	.....	18	22	29	40	49	55
	2	7	12	.....	.....	16	20	27	39	48	56
Average	.....	5.5	11.5	.....	.....	17	21	28	39.5	48.5	55.5
15°	1	8	18	28	39	50	61	76			
	2	10	21	31	39	48	55	67			
Average	.....	9	19.5	29.5	39	49	58	71.5			
20°	1	16	28	41	53	63	73	92			
	2	13	27	39	51	60	69	87			
Average	.....	14.5	27.5	40	52	61.5	71	89.5			
25°	1	17	34	48	61	75	90				
	2	19	34	48	60	74	90				
Average	.....	18	34	48	60.5	74.5	90				
30°	1	18	32	45	57	71	84				
	2	20	34	46	57	72	85				
Average	.....	19	33	45.5	57	71.2	84.5				

Steady increase in growth-rate is apparent up to 25° with a slight decrease at 30°. Bakke (6) places the optimum for *H. teres* as 23°—25°. Various changes in the appearance of the colony resulted from certain temperatures. Thus at 10° there was no zonation, no aerial mycelium, and very few conidia. At 15°, zonation was very faint, barely perceptible; at 20° and 25° more marked; while at 30° the aerial mycelium was very scant and zonation lessened.

Ravn (91) places the upper limit for growth at 33° — 34° ; the optimum at 25° — 30° ; the lower limit at 3° — 5° .

Plates prepared in a similar manner to the above were kept for 4 days at 15° and then transferred to the 25° case. Similarly, transfers were made from the 25° to the 15° case. The data of colony-growth from this trial are shown in the following table.

GROWTH OF H. NO. 1 IN ALTERNATING TEMPERATURES

Temperature	2 da.	3 da.	4 da.	Change of temperature to	5 da.	6 da.	7 da.	9 da.	13 da.
15°	8	18	31	25°	44	58	72	90	
	9	19	28		39	55	69	90	
Average.....	8.5	18.5	29.5	.....	41.5	56.5	70.5	90	
25°	17	32	48	15°	55	64	69	77	90
	18	31	47		54	63	71	78	90
Average.....	17.5	31.5	47.5	.....	54.5	63.5	70	77.5	90

The transfer to different temperatures made no perceptible difference in colony-character other than differences dependent on the rate of growth.

To ascertain the relation of temperature to the growth of H. No. 1 on live wheat shoots, this organism was planted as under standard conditions (App., page 180), except, of course, that the shoots were not autoclaved. Three temperatures, 15° , 20° , and 30° were used. When growth had proceeded to completion conidial length was found to be as shown in graphs of Fig. G. Conidia-production was scant at 30° , permitting only a few measurements. At the other temperatures it appeared to be normal. On these live shoots there was a marked shifting from the mean to the lower length as we passed from 15° to 20° , and a still more marked shifting at 30° (see Fig. G).

LIGHT

Two Petri dishes of corn-meal agar were inoculated with H. No. 1 and kept in the dark at 25° . In the following table the resulting growth is compared with that of similar plates kept in the light.

In darkness there was slightly less zonation and less aerial mycelium than in the light, but the difference was only slight and is probably insignificant.

To ascertain whether plate-position is an environmental factor of importance, numerous corn-meal agar plates were placed top up, others

bottom up, and observed carefully, but no difference in rates or characters of growth was observed.

GROWTH OF H. No. 1 IN THE DARK AND IN THE LIGHT

Temperature	Condition	Growth of colony-diameter (millimeters) at time-periods indicated					
		2 da.	3 da.	4 da.	5 da.	6 da.	7 da.
25°	Dark	21	32	44	56	71	85
		21	33	46	59	74	85
		21	32.5	45	57.5	72.5	85
25°	Light	17	34	48	61	75	90
		19	34	48	60	74	90
		18	34	48	60.5	74.5	90

CARBOHYDRATES

Brazil-nut agar in Petri dish with H. No. 1 gave snowy white colonies. When such colonies had reached a diameter of about 3 cm. one oese of powdered dextrin, maltose, rhamnase, or glucose was placed on the agar a few millimeters from the advancing edge of the colony. Within 48 hours the portion of the colony near the added carbohydrate, with the exception of rhamnase, produced conidia in much greater abundance than before, and the mycelium turned slightly dark. Starch, corn-oil, and corn-meal produced a similar effect, but with delay of nearly 48 hours, suggesting that the additional time required was needed for the production and action of enzymes, diastase, or lypase, as the case might be.

Again, plain-agar plates were poured and inoculated with H. No. 1, and when the colony was well developed various carbohydrate nutrients were laid on the agar near the advancing edge of the colony: steamed rice, steamed tapioca, 1 square centimeter of standard corn-meal agar, a fragment of a Brazil-nut, corn-starch, wheat flour, corn-meal, and buckwheat flour. All of these nutrients were used, and in each case the colony in the region of these nutrients turned black, owing to the quantity of conidia produced (Pl. XVI). Ravn (91) noted a distinct relation between carbohydrate nutrients and blackness in *Helminthosporium*, as did I in various fungi (118).

On plain agar, glyocoll and aspartic acid inhibited strongly at first, but later the fungus grew through these. It grew normally through tyrosine, glutamic acid, leucin, cystine, phenyl, and alanine without percep-

tible influence on the number of conidia, though as it approached corn-meal agar conidia-production became profuse.

NUTRIENTS AS AFFECTING CONIDIAL LENGTH, SEPTATION, AND SHAPE

Plates of washed agar when solid were inoculated with H. No. 1, and when the colony had grown to a diameter of about 3 cm. one of various nutrients was laid on the agar in approximately equal volume, at a distance of 1 cm. from the edge of the colony. When growth had ceased, graphs of conidial length were made. These graphs, with data sufficiently explanatory, are given in Fig. H. While the number of measurements made is too small to warrant any definite conclusion as to nutritive values, the obvious general conclusion is that the added nutrient did markedly affect conidial length. It is particularly noticeable that washed agar plus saccharose, tapioca, or rice gave small conidia, and in none of these cases was modal conidial-length equal to that of conidia grown under standard conditions (see Fig. K). Even the very striking modification represented by the bimodal curve shown in Fig. I was a product of environmental change. It was noted in the sample from which the graph was plotted that the conidia were produced in rather large clusters, the oldest one being largest, the others mostly much smaller. The minor mode here apparently represents conidia in a stage of arrested development, comparable with those of Graph 62 (Fig. O), while the major mode stands for conidia that approached more nearly to normal development but did not attain full size (cf. graphs of Figs. I and O with those of Fig. K). That the bimodality is not due to

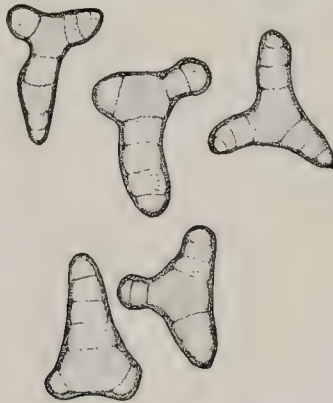


FIG. 4.—Tri-pointed conidia of H. No. 23 and H. No. 36 (see text, p. 102).

saltation is clear, since transfers made from these plates to wheat shoots (standard conditions; see App., p. 180) gave normal curves.

A striking temporary modification of conidial shape, due presumably to nutritive or osmotic conditions, was exhibited by H. Nos. 5, 23, and 36, in which a considerable number of the conidia were tri-pointed, owing to the central cell becoming inequilateral, then extending as is shown in Fig. 4. The fungus had long been cultured on rich carbohydrate agar, and when transferred to corn-meal agar these peculiar tri-pointed conidia were no longer common. (In this connection, see also page 154.)

SUMMARY CONCERNING ENVIRONMENTAL FACTORS WHICH INDUCE VARIATION

It is obvious from the foregoing record that very slight changes in environment may produce marked alterations in colony characters—growth-rate, color, aerial mycelium, clumping of mycelium, and even in the shape, septation, and size of the conidia. The quantity and concentration of nutrients, particularly of proteids and carbohydrates, have a very important influence on conidia-production and colony-color. Steinberg (114) and Javillier (69) have shown that even the zinc in the glass of the culture-flask has marked effect on the culture-characters. Dastur (40) has noted the following effect of media on *Gloeosporium*: after long culture on agar the conidia-bearing capacity is lost, though return to favorable media leads to its recovery unless the stay on agar has been too prolonged, in which case the capacity to bear conidia is completely lost. Air-humidity is especially significant as regards aerial mycelium, and has also an appreciable influence on the size of the conidia. Light seems of less importance, though experiments were insufficient with this factor to be conclusive. Temperature in the upper and lower ranges has a marked influence on many morphological characters.

In the light of the foregoing experiments it is clear that comparisons of colony-characters on artificial media should be made (especially as regards points of minor difference) only on media known to be as nearly as possible of the same composition, and, when practicable, upon the same lot of medium and at the same time: thus only can truly parallel conditions be secured. Petri dishes with flat bottoms should be used, and in order to secure equal thickness of medium the agar should solidify when level. Straw, leaves, etc., in test-tubes, give different quantities of aerial mycelium and conidia of different size at different levels, both of which are due to humidity and

nutrition differences. It is clear that conidia developed in the open on leaves or stems—some of the conidia in humid conditions, some in dry; some on leaves of rich nutrient value, others on those less nutritious—may differ materially in measurement owing to environmental differences; and similarly, it is clear that sclerotium-development is markedly influenced by slight changes in humidity.

Ravn (91) states that conidia measured from one plant were thicker than those from another, but whether this was due to environment or to actual differences in the fungi was not stated. He does, however, state definitely that in his groups conidia collected under different conditions showed different lengths; and that their length depends upon the conditions under which they developed. Examples of extensive modifications due to substratum are mentioned by Edgerton (50), Coons (33), Duggar (45), Moreau (84), and Burger (32). Variations similar to those herein noted as due to substratum, especially those due to the relation of carbohydrate nutriment to color and alteration of conidial mode were noted by me in 1909 (Stevens and Hall, 118). Brierley (26) denominates such variation "modal variation."

MORPHOLOGY OF THE FOOT-ROT FUNGUS

The parts chiefly to be considered, in the absence of knowledge of the ascigerous stage, are the mycelium, aerial, surface, and submerged, conidiophores, and conidia. Discussion of the relation of the mycelium in and to host-tissue will be given under the heading "Infection phenomena on wheat" (page 128).

This morphological study was made in part on the various media heretofore mentioned and on diseased plants in moist chamber. It was important, however, to have some means of securing the conidia, and other organs above specified, in large quantity, in form readily and conveniently available for examination. Moreover, the variability of the fungus under slight environmental changes emphasized the necessity of securing such morphological units as had developed under conditions as nearly identical and uniform as possible. This led to search for some standard means of culturing the conidia. Evidently corn-meal agar was unsatisfactory, since very slight changes in quality due to mode of preparation led to great morphological changes. Green-wheat agar and bean agar, both open to the same objection, also gave too much vegetative growth and too few and often abnormal conidia. Wheat in moist chamber, or wheat leaves or shoots in test-tubes varied so much in humidity that they could not give constant

morphological characters. The procedure finally adopted to secure standard conditions may be found in the appendix, page 180.

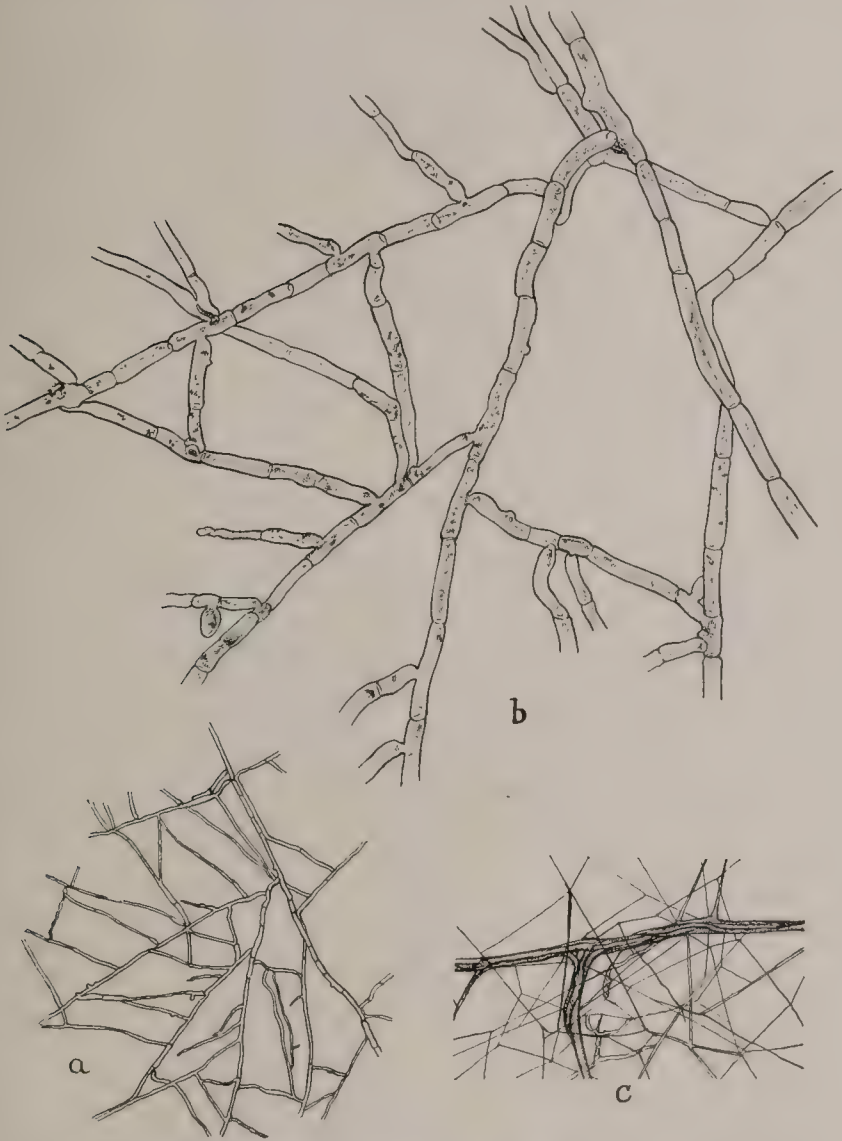


FIG. 5.—H. No. 1, showing extensive anastomosis of the mycelium where it coursed over bare glass: *a*, low-power view, *b*, detail of portion of *a*, high power; *c*, a bit of ropy mycelium composed of several twisted hyphae, many of the single threads undergoing dissolution.

MYCELIUM

The young, vigorous mycelium growing within the agar is smooth, quite straight, nearly or quite hyaline, and of very uniform diameter. The general aspect near the edge of a colony is shown in Fig. 6, *d*. In older parts of the colony the submerged mycelium is somewhat thicker and is less rich in protoplasm. The mature to old submerged mycelium has in agar a barely perceptible tinge of straw-color. The cells are quite strongly constricted at the septa and the content is highly vacuolate. Ravn (91) states that in the old immersed mycelium both plasma and cell-walls may be blackish green, grayish brown, or entirely black as in *Alternaria*. No such coloration as this has been observed in my cultures. The same author (91) discussing colony zonation, attributes it to variation in the color of the mycelium, while in my cultures it appears to be almost entirely due to variation in quantity of conidia and of aerial mycelium.

The quantity of aerial mycelium was highly dependent upon air-moisture and agar-conditions. When these favored there was a somewhat conspicuous, even floccose, white aerial mycelium 2 to 3 mm. high, consisting of either smooth, even, single filaments or, when quite abundant, of several filaments twined into a rope (Fig. 5, *c*). When conditions were less favorable the aerial mycelium, though inconspicuous, was still present in considerable quantity. The difference between various species of *Helminthosporium* and their saltants as regards the abundance of aerial mycelium is well shown in Plates IX-XIII. H. No. 36, a very distinct species from H. No. 1, was chiefly characterized by the great profusion of aerial mycelium (Pl. X). This character is the only one I have found by which to separate H. No. 1 and H. No. 3, and it serves only in the large cultures (Pl. IX-XIII), the distinction often failing in ordinary Petri-dish culture. The character is apparently so much modified by varying humidity as to make its utility for diagnosis of very questionable value (see pp. 95, 97). Ravn (91), however, distinguishes *H. avenae*, *H. gramineum*, and *H. teres*, growing on sterilized straw, by the different individual characters of the aerial mycelium and sclerotia; and *H. gramineum* and *H. avenae* on beerwort by the fact that *H. gramineum* forms a snow-white uniform mass of aerial hyphae, while *H. avenae* has sparse, white aerial mycelium which forms solid clumps, the black substratum-mycelium being visible between them.

The mycelium in wheat tissue is somewhat more irregular in contour than that grown in agar and is often much thicker. Occasionally upon the wheat surface it branched in a close fan-like fashion (Fig. 22, page 134). The

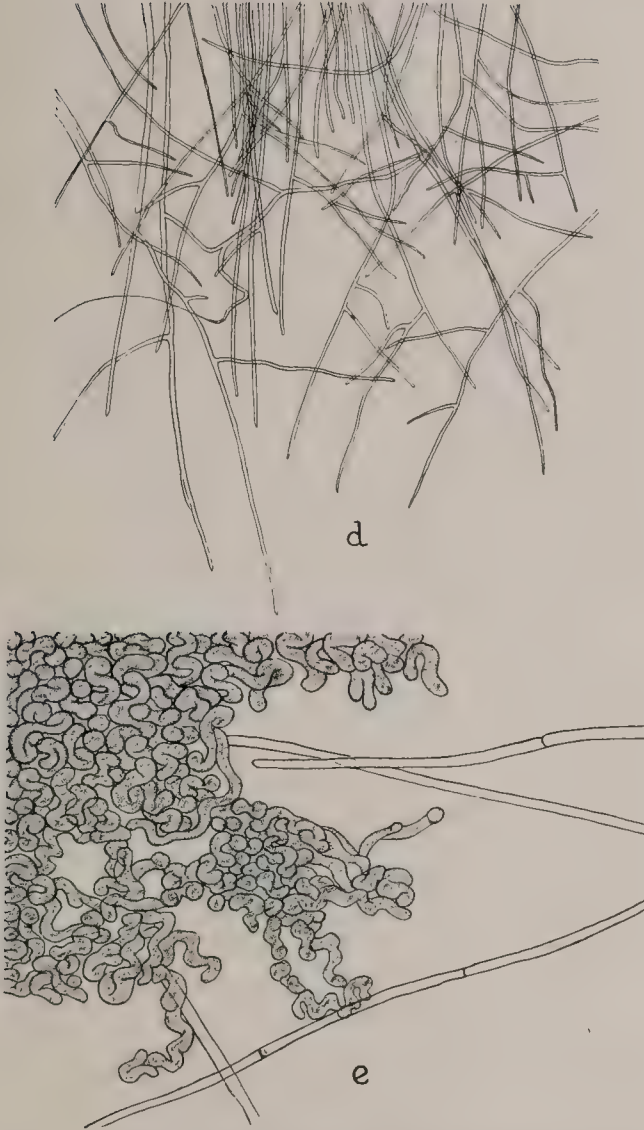


FIG. 6.—H. No. 1: *d*, showing branching and general appearance at edge of a colony growing on corn-meal agar; *e*, portion of a mycelial clump showing peculiar twisted character of the mycelium, with more usual strands for comparison.

aerial mycelium of some races produced clumps (Pl. XIII, XXII, XXIII), which under the microscope are seen to be due to a peculiar distortion and abundance of the aerial mycelial tips (Fig. 6, *d*). This peculiar behavior of the terminal parts of the mycelium shows some similarity to the branching figured by Ward (123) in *Botrytis* in the early stages of development of attachment organs. Anastomosis is very common with this fungus (Fig. 5, *a* and *b*), and Ward (123, fig. 19) has figured anastomosis of very similar character for *Botrytis*. Many citations of its occurrence are given by Beauverie and Guilliermond (13). (See also their figures 4 and 8.)

The nuclei in the mycelium are extremely small, but may be seen readily when stained with gentian violet, and still better if stained with iron-haematoxylin. They vary in number, but are never less than two and usually more; they do not typically group in pairs; and they are irregularly distributed in the protoplast. Nuclei apparently in mitosis are frequently seen, but since they are so small no details were noted except that the mitoses of all of the nuclei in one cell seem to be simultaneous, and mitosis was probable in adjacent cells. Reports on the nuclear conditions in the fungi imperfecti are few and unsatisfactory, doubtless owing to the extreme difficulty of the subject. Dangeard (39) notes nuclei and mitosis in the rather anomalous genus *Bactridium*; Beauverie and Guilliermond (13) in *Botrytis*; while Higgins (66) gives quite satisfactory figures for *Mycosphaerella*.

Senescence phenomena of aerial mycelium (Fig. 7, *a—b*).—When the aerial mycelium is young it constitutes a more or less abundant, loose, arachnoid, fluffy mass. In quite old cultures it is observed to mat down close to the surface of the medium in a thin, glazed, dead layer. Intermediate between these two extreme conditions interesting phenomena occur. The first observable change from that of the normal, vigorous mycelium is that certain cells of a filament, often many adjacent cells, become nearly or quite devoid of protoplasm (Fig. 7, *i*, *o*, and *g*), though cells at each end of such a series still appear normal (see *i* and *j*). Quite frequently the fungus re-grows from a protoplasmic cell, through the empty threads, as is shown in *n* and *o*. In other instances, and much more commonly, the empty cells gradually collapse until they remain as very thin, smooth filaments (*c*, *h*, and *m*), apparently of gelatinous texture. Where two filaments undergoing such dissolution cross they blend (*a*, *b*, *m*); and where several meet, rather large amorphous unorganized masses are seen, superficially much resembling a plasmodial structure (*a*). There was, indeed, at first, suspicion that there might be present a plasmodial

parasite preying upon the *Helminthosporium* mycelium; but numerous tests convinced me that such was not the case, but that what really occurs is that the old aerial mycelium dissolves (probably by auto-digestion). All stages of this disorganization can be followed under the immersion lens in stained preparations, where the disorganized filament stains with the gentian violet but is seen to be amorphous and without protoplasmic content. These phenomena appear to be limited to the aerial mycelium, but were

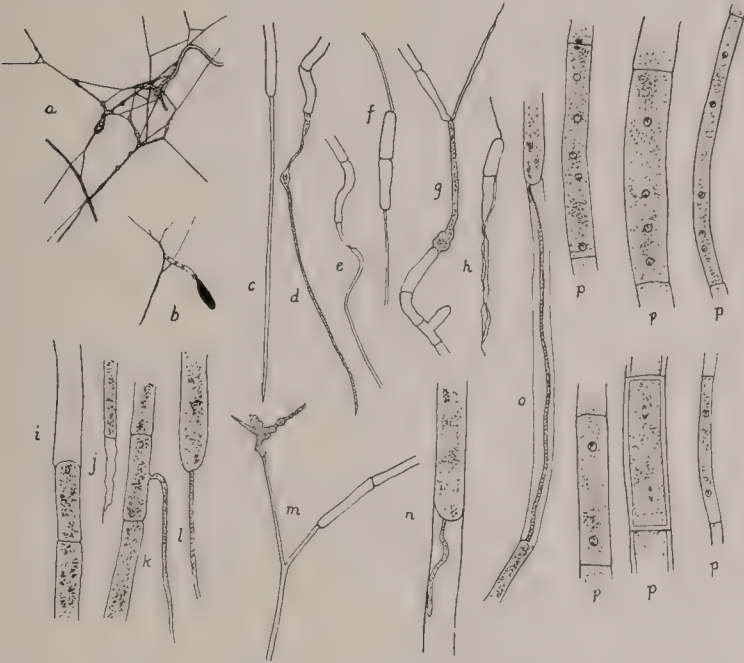


FIG. 7.—Various views (*a* and *b*, low power, *c*—*o*, high power) of mycelium of *H.* No. 1 in senescence: *a* and *b* showing dissolution to fine threads, *b* with a conidiophore still attached; *c*—*h* and *m*, empty mycelial cells adjacent to cells nearly dissolved; *i* and *j*, protoplasmic cells adjacent to empty cells; *k* and *l*, fine mycelial outgrowths from protoplasmic cells; *n* and *o*, fine mycelial threads growing from the protoplasmic cells and through old empty cells; *p*, bits of mycelium, as seen with the immersion lens, showing the nuclei.

observed on many strains of *Helminthosporium*. Autodigestion of mycelium doubtless occurs in the case of wood-rotting fungi, as is evidenced by the absence of mycelium where it was previously known to be, and it may be of common occurrence in other fungi. It certainly occurs when two hyphae join by anastomosis, and in the union of sexual organs. Growing-through of the mycelium, as noted above, and even conidia-formation within the old cell are common in *Saprolegnia*, and have been noted in

several other genera: *Botrytis* (Beauverie and Guilliermond, 13); *Alternaria*, *Epicoccum*, and *Botrytis* (Linder, 78); *Inzengaea* (Borzi, 23); *Dematium*, *Botrytis*, *Oidium* (Klöcker and Schiorming, 75); *Chaetomium* (Zopf, 129, figs. 24, 25, A, B, Tab. 16). The phenomenon, as described, is always associated with senescence. Sclerotia are described by Bakke (6) and by Noack (87), who seem to have found them common on old straw-cultures, varying in length from 200 to 600 μ . I have not found them at all on straw, though on old rice-cultures they are abundant. Pycnidia and pycnoconidia, as seen by Ravn (91) in *H. teres* and as described by Bakke (6), I have not seen.

CONIDIOPHORES

On standard wheat-shoots.—The conidiophores are in no sense clustered but arise singly as lateral branches, each from an ordinary mycelial cell, and differ from the mycelium chiefly in that they grow erect and straight instead of declined and crooked, and are darker in color than the mycelium. Usually this branch in its basal region is mycelium-like, but it rapidly thickens and darkens to true conidiophore character, and is usually 2.5 to 5 μ in length. Sometimes the mycelial cell from which the conidiophore arises also darkens. The conidiophore-cells contain protoplasm, and the protoplast plasmolizes under the usual reagents. When mature the conid-

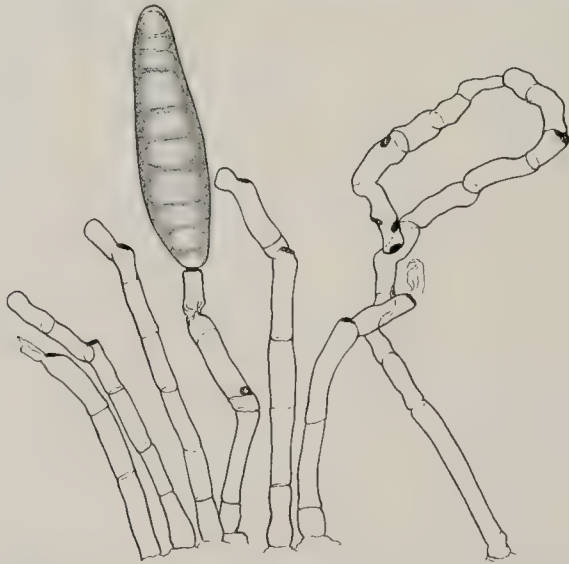


FIG. 8. — II. No. 1, showing variation in conidiophores, geniculation, conidia-scars, and septation.

iophores are pale straw-color to smoky brown from tip to, or nearly to, the base, the color being due to the outer wall—which is very brittle. Upon the production of the first conidium, which is strictly terminal, the conidiophore grows onward, with a slight bend where the first conidium was produced, and proceeds to bear another one. This may continue until many conidia have been borne by the same conidiophore. If the conidia are undisturbed, the cluster may have a botryose effect, but if disturbed, only the youngest conidia remain, and scars and geniculations mark the places of origin of the fallen conidia (Fig. 8). The number of conidia borne per conidiophore in count of 24 was as follows:

Frequency,	15, 5, 4
Conidia,	1, 2, 3

Much higher numbers than this occasionally occurred under standard conditions (see appendix, page 180); and much higher numbers were the rule on corn-meal agar.

The number of septa below the first scar varied from one to four, while the length in seven measurements from base to first scar was 78—88 μ . The length above the first scar is entirely dependent upon the number of conidia borne on a given conidiophore; in some cases it is equal to or even greater than the length below the first scar.

Conidia develop very rapidly upon the conidiophores. One of the latter kept constantly under observation was first observed at 11 o'clock to have a diameter of 6.8 μ ; at 11:15, 13.6 μ ; at 11:30, 20.4 μ ; at 12, 37.4 μ ; and at 12:30, 44.2 μ .

The conidiophores of certain other numbers, for example H. Nos. 2, 21, and 29, are of such very different character that the conidiophores alone serve to distinguish them markedly from H. No. 1. The conidiophores of H. Nos. 3, 5, 15, 16, and others, however, are closely like those of H. No. 1; indeed no real distinction could be found between them. Attempts were made to distinguish between these strains or species by plotting conidiophore length, septation, length of cells, etc., but nothing came of such attempts. The length of the conidiophore is markedly influenced by air-humidity (page 95), and it is probable that the rudimentary conidiophores may be changed into aerial mycelium by a lowering of the air-humidity.

CONIDIA

The conidia and their attachment to the conidiophores are shown in Plate XVII. From the basal end of the conidium to the conidiophore there is an exceedingly short ($2 \times 4 \mu$) black stipe. As the conidium falls

away from the conidiophore the stipe remains attached to the conidium, and as it can always be seen readily when the conidium is in suitable position, it serves as a ready means of recognizing the basal end of the conidium. The stipe is equally obvious and distinguishable in H. Nos. 3, 4, 5, 13-16, etc., though in H. No. 2 and certain other numbers the stipe is of somewhat different type. While in very rare instances catenulation of conidia was observed (Fig. 9, *b*), this is apparently much less frequent than in the forms

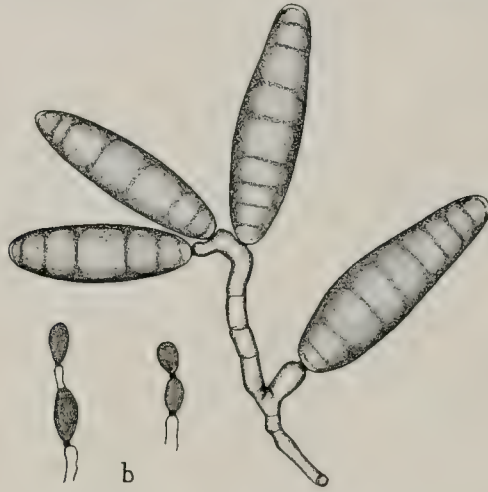


FIG. 9.—H. No. 1: *a*, portion of a conidiophore bearing conidia; *b*, catenulate conidia—rarely occurring.

described by Ravn. The apical end of the conidium is always obtuse, and is marked by a pale spot that was mentioned by Ravn (91) as occurring in *H. teres*, etc. Being of so distinctive a character, this end is always recognizable when the conidium is in a suitable position. We have, then, reliable means of identifying each end of the conidia: the basal stipe and the apical spot (Fig. 10). The latter, though not characteristic of all *Helminthosporium*s—for example, H. Nos. 2, 29, and others lack it—is characteristic of H. Nos. 1, 3, 13-16, and others.

The color of the conidia of H. No. 1 ranges from pale-straw to light brown, and under some conditions shows a slight bluish-green tinge. While H. Nos. 2 and 28 were distinctly and constantly different from H. No. 1 in color, H. Nos. 1, 3, 13-16, etc., were indistinguishable on a color basis.

The conidial outer wall.—This wall (the episporium of de Bary, 9), which gives the color to the conidium, is extremely thin and very fragile

(Pl. XVIII). It is so brittle that by gently tapping the cover-glass over conidia the outer dark wall of every one of them may be broken in fragments, much as a peanut is broken if stepped upon. This character is common to H. Nos. 1, 3, 5, 13-16, etc., as well as to H. No. 2, and many other species, though in some the wall is less brittle than in others. The conidial wall that is left after the solution of the endosporium by sulfuric acid is entirely without sign of septation, but shows the apical spot clearly differentiated as a thin pale region.



FIG. 10.—Variation in conidial shape and septation of H. No. 1, and showing also the dark spot, stipe, at basal end, and the pale apical spot.

Conidial contents.—Within the thin colored wall are the protoplasts, usually several in number (Fig. 11), and between the protoplasts and the outer wall is a thick hyaline layer of substance that is somewhat soft, usually appearing almost gelatinous (Pl. XVIII). This hyaline soft layer represents morphologically, I believe, a second cell-wall, the endosporium of de Bary (9). I shall so speak of it. That this wall is soft is shown by the way the conidial contents issue from the end of a cracked conidium under pressure

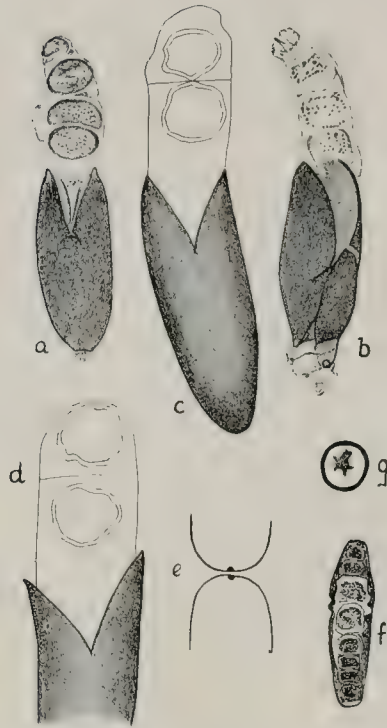


FIG. 11.—Conidia of *H. No. 1*: *a* and *b*, with outer wall cracked open by pressure, the inner hyaline wall and the protoplasts emerging; *c*, another conidium with the outer wall crushed by pressure, the two protoplasts walled and touching; *d*, similar to *c*, but with the protoplasts separate; *e*, immersion-lens view of two protoplasts within a conidium, showing thickening at their point of nearest approach to each other; *f*, a longitudinal microtome-section of a conidium from which both sides have been cut away; *g*, a cross-section of a conidium showing much clear space between the protoplast and the outer wall.

(Fig. 11). De Bary (9) remarks that the endosporium often shows great softness and delicacy but is by no means always thinner than the other wall. That the outer conidial wall has no internal ridges, and takes no part in forming septa, is shown both by direct observation and by inference from the way in which the conidial contents slide, unobstructed, lengthwise of, and out of, the outer conidial wall. Ravn (91) states that in the three species studied by him the walls and septa are very thin, but when treated with glycerine, etc., the outer wall becomes prominently thickened,

as also the cross walls where they meet the outer wall. In making this statement he refers to the episporium and endosporium as constituting two layers of one wall. In some instances the endosporium is clearly seen to extend between, and to separate, the protoplasts (Fig. 11, *b*), while in other cases the protoplasts appear to touch each other (Fig. 11, *a*), yet when the conidial contents are pushed from a crushed conidium there is always a line, though sometimes it is very thin, separating the protoplasts. Since the protoplasts are distinct from each other, and are thus separated by the endosporium, it seems justifiable to assume that this second cell-wall forms the septa, sometimes obvious though very thin, between the protoplasts. Treated with concentrated sulfuric acid the conidial endosporium dissolves rapidly, and by the generated pressure the episporium is ruptured, invariably at the basal end first, this often opening trap-door-like, though frequently the pressure is sufficient to tear the wall of the conidium open throughout its length. With the solution of the endosporium the protoplasts issue from the case of the conidium and appear to be unattached.

The individual protoplasts vary much in shape, sometimes being nearly spherical; in other cases nearly cubical. Each protoplast is surrounded by a differentiated layer which in some cases is so clear, distinct, and thick as to appear to be a third wall (Fig. 11). Perhaps it is. Under gentian violet and many other aniline stains, while the protoplast takes a strong stain this layer refuses to stain. Microtome cross-sections and longitudinal sections of conidia verify the foregoing conclusions (Fig. 11, *f*). In cross-sections (Fig. 11, *g*), with Fleming's triple stain the protoplast stains as usual, but the second cell-wall refuses to stain; under Bismarck brown it takes a very faint stain. Under action of aniline blue, iodine, fuchsin, malachite green, Pianese, or chlor-zinc-iodine it remains unstained. In longitudinal sections cut so thin that two sides of the conidium have been cut away, mature conidia show no continuity of the protoplasts (Fig. 11, *d*). When plasmolized the protoplasts all shrink and lie quite separate from each other, and it is in such condition that the appearance of a third conidial wall is most evident (Fig. 11, *a, b*). Previous to plasmolysis the protoplasts are frequently seen to touch each other on the median longitudinal axis of the conidium, and a very faint line (plane) is observable extending across the conidium (Fig. 11, *a, b*). This probably represents the true septum, following nuclear division. The protoplast wall bears a small dot-like thickening (Fig. 11, *e*) adjacent to its sister protoplast, which may also be residual evidence of nuclear mitosis.

The characters as here given for H. No. 1 are found also in such re-

lated forms as *H.* Nos. 3, 13, 16, etc. That the internal structure of *Helminthosporium* conidia has not been clearly understood is shown by numerous published figures.

Conidial germination.—The conidia germinate readily in water, in hanging drop, or on the surface of wheat shoots (Fig. 12), and germination,



FIG. 12.—Germinating conidia of *H.* No. 1

so far as I have seen, is very rarely lateral but usually from the ends, most commonly from the basal end. Thus twenty-seven basal germinations were counted as against fourteen apical ones. The germ-tube is hyaline, richly filled with protoplasm, and forms abundant branches and septa (Fig. 12). Bakke (6) states that "germ tubes first come from basal and apical cells; later other germ tubes may arise from the remaining cells under favorable conditions." Kirchner (72) states that germination in *H. gramin-eum* is usually terminal, but Noack (87) shows that for this species the germ-tubes are as often lateral. The viability of the protoplast was not injured by crushing the episporium; indeed such cracking seemed to facilitate emergence of the germ-tube. Anastomosis of the germ-tubes is not uncommon (Fig. 13). As the germ-tube enlarges there is frequently, though not

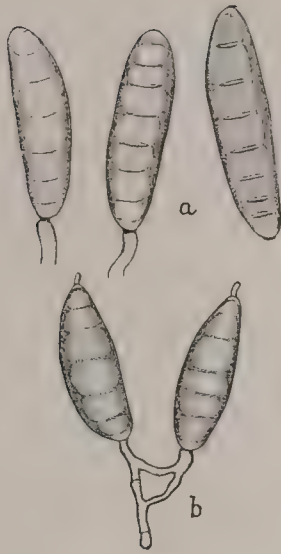


FIG. 13.—Conidia of H. No. 1:
a, showing septa from two
 depths of focus; *b*, two germinat-
 ing conidia with germ-tubes
 anastomosing.

always, shrinkage of the protoplasts such as is shown in Fig. 11, this shrinkage being usually most pronounced in the end of the conidium showing most vigorous growth. To all appearance the endosporium serves as a stored food and is consumed in germination, since its presence in much diminished quantity in germinated conidia is evident when such conidia are crushed. The conidiophore-cells also occasionally function as conidia by sending out a germ-tube. Here, too, the inner cell-wall seems to serve as reserve food.

Longevity of conidia.—It is not known how long conidia live, but on wheat straw that had remained air-dry for fourteen months they germinated normally. Noack (87) mentions germination "after many months." Ravn (91) says of three species that at eight months they germinated but sparingly or not at all.

Frequency of conidial septa.—H. No. 1 under standard conditions (see appendix, page 180) gave the graph in Fig. J, while similar data for H. Nos. 13-16 are given in Fig. T.

Septa	Differences of means of septa
H. Nos. 1 and 3.....	0.27 $\pm$.16
H. Nos. 1 and 15.....	0.80 $\pm$.12
H. Nos. 1 and 16.....	0.58 $\pm$.11
H. Nos. 15 and 16.....	0.22 $\pm$.11

It is to be noted that the differences between Nos. 15 and 16 are quite as large relative to the probable error as are the differences between Nos. 1 and 3. Ravn (91), speaking of three species of *Helminthosporium*, says that the septa are very variable, and that specific differences can not be derived from them. Very abnormal septation was frequent; for example, on green-wheat agar (Fig. 14) and other uncongenial media.



FIG. 14.—Various abnormal conidia of H. No. 1 as grown on green-wheat agar.

Conidial shape.—The shape of the conidia, together with their size and septation, are in the genus *Helminthosporium* the three most-used characters in description. Indeed in published descriptions of many species these are the only important characters mentioned, and often one or more of these is lacking. Conidial shape in certain species is very characteristic, particularly in *H. inaequalis*, *H. geniculatum*, *H. ravenelii*, and also in my H. No. 29. Much stress has been laid on conidial shape as a means of distinguishing certain cereal *Helminthosporiums*, particularly in distinguishing *H. sativum* from *H. teres*.

Merely to look at two lots of conidia with the microscope, even with the aid of a comparison ocular, is not a satisfactory means of ascertaining the prevailing conidial shape. Many strains of *Helminthosporium* vary greatly as to conidial shape, and conidia of one shape are mixed with those of another (Pl. XIX–XXI). The important question is, what is the relative frequency of the various shapes? But before any fair estimate of this can be made, standards must be established as to what are the essential characters of the various shapes.

One factor of preponderating influence in determining these conidial shapes is the position that the point of greatest diameter occupies on the

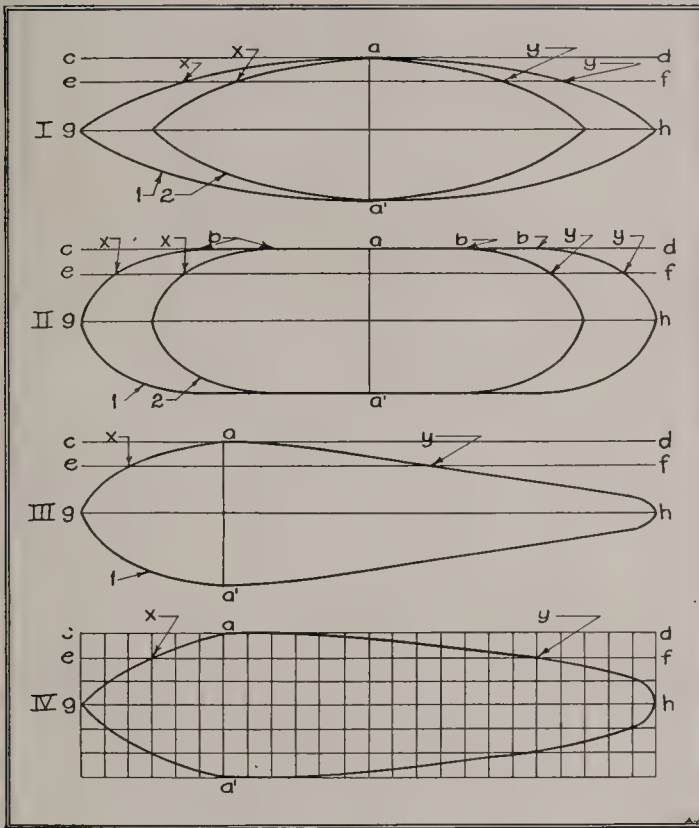


FIG. 15.—Diagrams elucidating conoidal shape.

longitudinal axis of the conidium. In diagrams I and II, Fig. 15, the point of greatest diameter on the line $a—a'$ is midway between the base and apex of the conidium; while in diagrams III and IV it is nearer to its base. If the conidium tapers from the point of greatest thickness toward each end a fusiform (Diagr. III) or elliptical (Diagr. I, 1, 2) conidium results. If for a sufficient distance on each side of the line $a—a'$ the conidium remains of uniform diameter it approaches more nearly the form of a cylinder (Diagr. II, 1, 2). When the maximum diameter is nearer to the base than to the apex, somewhat rapid tapering gives a fusiform conidium (Diagr. III), but if (as in Diagr. IV) the diameter lessens very gradually, as from the point a to point y , the conidium may be said to be subcylindrical.

Mere casual observation of many strains of *Helminthosporium* showed that the point of maximum diameter was usually near the basal region of the conidium, occasionally near the middle region, while in extremely rare cases it was near the apical quarter, the ratio of these cases being for H. No. 1 about 30:14:4. A more accurate determination of what may be termed the longitudinal eccentricity of the conidium—that is the range of variation in the position of the line of greatest diameter ($a-a'$, Diagr. I—IV) may be made by measuring (along the longitudinal axis) the distance from the base of the conidium to the intersection of the line $a-a'$ with the longitudinal axis. This distance divided by the total length of the conidium may be known as its *coefficient of longitudinal eccentricity*. This coefficient for H. No. 1, based on 65 conidia taken at random, was found by the above method to be $.43 \pm 0$. In other terms the point of maximum diameter was distant from the base of the conidium 43% of the total length of the conidium. Bakke (6) says that the conidia of *H. teres* are widest at the middle. The coefficient of longitudinal eccentricity based on 11 conidia of H. No. 1 which were of typical subcylindrical appearance (approaching that shown in Diagr. IV) was .45 as contrasted with a coefficient of .43 for 11 conidia of elliptical appearance (Diagr. I). Coefficients of longitudinal eccentricity for H. Nos. 5, 20, and 4 of subcylindrical shape, were respectively .35, .39, and .37, showing that in these forms the point of maximum diameter is slightly nearer the base than it is in H. No. 1. None of the conidia of H. No. 1 was truly cylindrical, that is, the sides were not parallel for any appreciable distance. Many were subcylindrical, the form approaching that shown in Diagram IV. Of 65 conidia taken at random 81%+ of the conidia were elliptical; 17%+ subcylindrical; and 1% otherwise.

To secure a coefficient which would indicate with some degree of accuracy the curvature of the conidial wall (as from point a to point y , Diagr.

I—IV) determinations were made of the ratio $\frac{xy}{gh}$ (Diagr. I—IV). The line cd was tangential to the surface of the conidium at the point of maximum diameter, and was parallel to the longitudinal axis of the conidium, the line ef being 3.4μ from the line cd and parallel to it. Then the points x and y are where the surface-line of the conidium cuts the line ef . It is obvious that as the line xy increases in proportion to the length of the conidium, gh , the conidium more nearly approaches the form of a cylinder; and as the line xy becomes proportionately shorter the conidium becomes less like a cylinder. The ratio $\frac{xy}{gh}$ may therefore be termed the coefficient

of cylindricity. For these determinations only conidia of approximately modal length were used, and to obviate unconscious selection, measurements were made of only the left side of the conidium, the basal end being toward the observer. Determination from 11 conidia of H. No. 1 of subcylindrical shape gave a coefficient of .74, while that from 53 elliptical conidia was .67.

The above findings for H. No. 1 are as follows:

<i>Coefficient of longitudinal eccentricity</i>	
All conidia.....	.43
Elliptical conidia.....	.42
Subcylindrical conidia.....	.45
<i>Coefficient of cylindricity</i>	
All conidia.....	.70
Elliptical conidia.....	.67
Subcylindrical conidia.....	.74

Determinations of the coefficient of cylindricity made from drawings of Dr. Ravn (91) gave for *H. gramineum* and *H. avenae* respectively .86 and .95, showing a much higher coefficient than is given by any of the forms in my collection.

A convenient method of measuring conidia for coefficients is given on page 179 of the appendix.

Conidial length.—From five separate plates, *a*, *b*, *c*, *d*, and *e*, inoculated with H. No. 1 under standard conditions, Graphs 36-40 (Fig. K) of conidial length were made. Two additional graphs were made from plate *e*, one of which is designated as *e'*. The data pertaining to these graphs are given with the others (Fig. K).

The differences between the means of conidial length on plates *a* to *e* and *e'* are as follows:

<i>Plates</i>	<i>Differences between means</i>	<i>Plates</i>	<i>Differences between means</i>
<i>a-b</i>	+0.70 $\pm$.21	<i>b-e'</i>	-0.19 $\pm$.16
<i>a-c</i>	+0.62 $\pm$.24	<i>c-d</i>	+0.16 $\pm$.23
<i>a-d</i>	-0.78 $\pm$.23	<i>c-e</i>	+1.40 $\pm$.24
<i>a-e</i>	+2.03 $\pm$.24	<i>c-e'</i>	+0.11 $\pm$.17
<i>a-e'</i>	+0.50 $\pm$.16	<i>d-e</i>	+1.24 $\pm$.25
<i>b-c</i>	-0.07 $\pm$.22	<i>d-e'</i>	-0.28 $\pm$.18
<i>b-d</i>	+0.08 $\pm$.23	<i>e-e'</i>	-1.52 $\pm$.19
<i>b-e</i>	+1.32 $\pm$.24		

Since the various plantings on these plates were all from the same inoculum, made at the same time, and under as nearly identical conditions as possible, and so kept, the rather large difference in means seen, particu-

larly in $a-e$, $b-e$, $c-e$, $d-e$, and $e-e'$ is significant. If plate e be left out of consideration, the others agree reasonably well, with differences greater than the probable error in six out of ten cases, the difference being but slightly above the probable error in two cases, about twice the probable error in two cases; and about thrice that, in two cases, the largest excess, in plates $a-b$, being $0.70 \pm .21$.

Plate e deviates widely, with a difference in case of $a-e$ of $2.03 \pm .24$, the difference being more than eight times the probable error. The great difference in plate e must indicate variability of the fungus on this plate (cf. with page 152), modification due to influence of some unknown factor of environment, or error in sampling. But since such a variation did occur in a series of plates made with the greatest care and with the same organism, it is clear that the occurrence of such a difference can not properly be interpreted as meaning specific difference. Data from the combined records of a , b , c , d , and e' (omitting e as questionable) give the most reliable data I have on length of conidia of *H. No. 1* under standard conditions (cf. with Graph 42, Fig. K).

To determine how wide a variability occurs in specimens collected in the open, on the natural host, *H. ravenelii* (Pl. XX) a well-marked, easily recognized species of wide geographic distribution, growing on *Sporobolus*, was studied in conidial-length graphs made from specimens listed in connection with the graphs (Fig. L). The tabulated results of this study of *H. ravenelii* follow:

Nos.*	Differences between means	Nos.*	Differences between means
43—46	$0.48 \pm .26$	46—50	$0.50 \pm .28$
43—47	$0.59 \pm .24$	46—51	$0.70 \pm .28$
43—49	$0.62 \pm .28$	46—52	$1.46 \pm .28$
43—48	$0.62 \pm .29$	46—53	$2.43 \pm .27$
43—50	$0.98 \pm .27$	47—51	$0.59 \pm .26$
43—51	$1.18 \pm .27$	47—52	$1.35 \pm .26$
43—52	$1.94 \pm .27$	47—53	$2.33 \pm .25$
43—53	$2.92 \pm .26$	48—51	$0.56 \pm .30$
44—48	$0.45 \pm .31$	48—52	$1.32 \pm .30$
44—49	$0.46 \pm .31$	48—53	$2.30 \pm .29$
44—50	$0.81 \pm .30$	49—51	$0.55 \pm .29$
44—51	$1.01 \pm .30$	49—52	$1.31 \pm .29$
44—52	$1.77 \pm .30$	49—53	$2.29 \pm .29$
44—53	$2.75 \pm .29$	50—52	$0.96 \pm .29$
45—50	$0.80 \pm .24$	51—52	$0.76 \pm .29$
45—51	$1.00 \pm .25$	51—53	$1.73 \pm .28$
45—52	$1.76 \pm .25$	52—53	$0.97 \pm .28$
45—53	$2.74 \pm .24$		

*For significance of numbers, see Figure L.

A difference of $0.97 \pm .28$ between the means of two samples from the same specimen (Nos. 52 and 53)—a difference more than three times the probable error—shows clearly the difficulties of sampling, and that such differences between samples of the same species grown under the same conditions may be expected. The differences in several instances, notably between Nos. 44 and 49, 44 and 48, and 46 and 51, are no greater than those between two samples of the same specimen and may well be due to sampling, and to this extent show the fungus, over a wide geographic range, to be remarkably uniform. In several other instances, however, there is a wide difference of means, above the probable error—notably in all cases involving sample No. 53. These differences are often four, five, or six times the probable error, and occasionally run as high as eleven or twelve times the probable error even with this remarkably uniform fungus. While these differences may in part be attributed to sampling they probably represent also morphological changes due to environmental differences, and differences of nutrition or humidity, but do not necessarily indicate racial difference in the fungus.

To determine whether various cereals, autoclaved, influence conidial length differently, plates of H. No. 1 were prepared under standard conditions except that in the same Petri dishes were placed shoots of wheat, rye, barley and corn. The resulting graphs of conidial length are given in Fig. M. The differences in means are as follows:

On rye and wheat, $0.40 \pm .29$
 On rye and corn, $0.45 \pm .20$
 On wheat and corn, $0.02 \pm .22$

The mean length on rye, corn, and barley is in close agreement with that on wheat, and, apparently, under these conditions the species of shoots counts for little in its influence on conidial length.

Conidial-length graphs (Fig. N) made from H. No. 1 grown on fresh wheat-stems, on young wheat shoots, on wheat leaves, and on young wheat plants, all autoclaved in test-tubes with a few centimeters of water, show a considerable increase over those under standard conditions (Graph 42, Fig. K); also, in Graphs 58, 60, and 61 (Fig. N), they show a much larger standard deviation and coefficient of variability, probably due to the variable humidity under these conditions. The small number of conidia measured, and the lack of control over humidity may be presumed to account for such variation as is seen.

Live wheat inoculated in rag doll showed at the 6th day 100% infection. These infected seedlings were placed in a Petri dish on moist filter-

paper and the conidia allowed to develop to maturity. Conidial length here (Graph 64, Fig. O) was somewhat less than under standard conditions (see Graph 42, Fig. K), and the coefficient of variability was a little high.

Conidial breadth.—H. No. 1 was quite constant in conidial breadth as follows:

M	σ	CV
6.03 $\pm$.04	0.55 $\pm$.34	9.13 $\pm$.57

The ratio of conidial length to conidial breadth is an important one as determinative of shape. This ratio for H. No. 1 is as follows:

$$\frac{\text{mean length}}{\text{mean breadth}} = \frac{22.62 \pm .05}{6.03 \pm .04} = 3.74 \pm .03$$

In a description of H. No. 1, written in May, 1919, for my own use, and prepared with considerably more care than is ordinarily used in specific descriptions of fungi, I noted the conidia as 3—8 septate and as 52.6—67.2 $\times$ 19.2—24 μ long on wheat; and as 48—84 $\times$ 18—21.6 μ on corn-meal agar, whereas my more extended study now shows the mode on wheat as 78.2 μ , the mean as 76.8 μ , and the range from 34 to 98.6 μ ; the breadth as ranging from 17 to 23.8 μ , with the mean as 20.4 μ ; the septa with a mode of 8, a mean of 7.9, and ranging from 4 to 10. I may here note also that Bakke (6) in his description of *H. teres* gives the conidial dimensions as 150 [or 105*]—130 $\times$ 15—20 μ , and the septa as 7—14. Thus he seems to have found conidia considerably longer than I did, as also narrower ones. It should be said that the data obtained by this study of graphs of H. No. 1, though involving several thousand measurements, fail to record the longest conidium observed, and the one with the most septa, because these were both seen during observations which rendered their inclusion impossible; which is to say that to include them would have been to consciously *select* these unique conidia for inclusion. Anent the shortcoming of my own brief description cited above may be quoted the Saccardian description of *H. ravenelii*: "Spongiosum; hyphis flaccidis flexuosis nodosis ramosis, inarticulatis; conidiis cymbiformibus, 3-4 septatis, fuscis, 50 μ longis, endo-chromotibus isthmo connexis." Though the mode is approximately at 50-54 μ the conidia really range from 13 to 71 μ (see Fig. L). Very similar errors, due to brevity of description, exist regarding many or all known species.

*See Pammel, King, and Bakke (90, p. 180).

ETIOLOGY OF FOOT-ROT

EVIDENCES OF ETIOLOGICAL RELATION OF H. NO. 1

Constant Presence of the Pathogene

In all cases of American foot-rot of wheat that have come under my observation the rotten basal portion of the shoot bore and was to a large extent occupied by a mycelium, which grew luxuriantly within the wheat tissue though very sparingly upon its surface, coursing lengthwise within the diseased cells. This mycelium was hyaline, septate, vacuolate, irregular in thickness, and, in short, agreed in all characters with those of H. No. 1 when growing in rotting wheat-tissue (page 105).

Absence of other Constant Parasites

No other organism which might be considered as a possible parasite was present in any large number of cases in or on the wheat tissue. Amebae and nematodes were present in great numbers in the soil, but appeared to bear no relation to the rot of the wheat. Various fungi, as *Fusarium* (two species), *Rhizoctonia*, *Epicoccum*, *Alternaria*, were occasionally found on the roots or stems, but each only rarely, in a fraction of 1% of the cases, and with no evidence of etiological relation to the rot of the stem.

Identity of Pathogene proved by Culture

Very numerous isolations were made by taking bits of tissue (1) from diseased sheaths, (2) from diseased stem-lesions, and (3) by stripping away the sheath, disinfecting the remaining surface with mercuric chloride and taking out diseased bits, with precautions against contamination. All such diseased bits were laid on the surface of corn-meal agar plates. Hundreds of these were made, with the result that in practically every instance the diseased bit gave rise to *Helminthosporium* conidia in general aspect like those of H. No. 1. Other organisms, as mentioned, occasionally occurred on these plates, but in only a small per cent. of instances. It seems entirely conclusive that the mycelium constantly found in the rotting basal portion of the diseased wheat-stems is that of a *Helminthosporium*.

Evidence of Infectiousness

Several bags of soil that bore diseased wheat in 1919, near Granite City, Illinois, were brought into our greenhouse in July, 1919. In this soil was planted "Sultzer Pride" wheat, and the planting kept liberally watered. At the end of some weeks the plants were removed, and on examination all

showed browning and incipient rot of the basal portion of the stem. Microscopic examination and agar platings from these stems gave results identical with those stated above. One plant that was so badly rotted in the pot as to fall over was found bearing *Helminthosporium* conidia on its surface.

Conidia produced in Moist-chamber Culture

While stems with diseased lesions, either from the field or greenhouse, when placed in an ordinary moist-chamber rarely gave *Helminthosporium* conidia (or, if they did, only in small numbers), if the diseased stems were placed on wet filter-paper in moist chamber and rather closely covered with wet filter-paper *Helminthosporium* conidia invariably developed in quantity on the lesions, the fungus eventually spreading throughout the available wheat-tissue and producing conidia over the whole surface (cf. with page 95).

Evidence from Inoculation

Severed, live wheat-shoots, grown under aseptic conditions, were placed as under standard conditions (Appendix, page 180), except that the shoots were not autoclaved but put, living, upon the inoculated agar. All such shoots rotted rapidly and completely, the shoot being eventually covered by *Helminthosporium* conidia. Since direct examination showed no contamination, it is evident that H. No. 1 can cause rot of the wheat tissue.

To determine the relative rotting power of this organism and other *Helminthosporium*s under these conditions, fresh aseptic shoots of corn, wheat, oats, barley, and rye were laid on washed agar with the growing tip toward the circumference of the dish, and the cut end in contact with the outer edge of the spreading mycelium of a colony about 5 cm. in diameter. These were examined after 2 days and again after 5 days, and the rate of browning was carefully calculated. In this way seventeen strains of *Helminthosporium* were tested as to their ability to produce rot in live, severed cereal-shoots. H. No. 1, the foot-rot organism, showed high rotting ability, completely rotting a wheat shoot 11 mm. long in 5 days, while H. No. 2 (*H. ravenelii*) produced no rot on any cereal. H. No. 1 rotted corn also, but much less rapidly than it did wheat, and its rate on oats, barley, and rye was still less. Several other numbers showed strong rotting power on wheat shoots, notably H. No. 10 (labeled *H. teres*), isolated by Dr. Stakman from barley, H. No. 9 isolated by him from wheat, and H. No. 13 (labeled *H. sativum*), isolated by Dr. Durrell from barley.

The results from this preliminary work indicate also a very wide difference in the susceptibility of these cereals to rot by the various strains of *Helminthosporium*. Oats, on the whole, are less injured by them than any of the other four cereals tested. Corn and wheat were most often first in susceptibility to certain of the strains, and were also highly susceptible to more strains than were barley and rye.

Seedlings in Petri dishes inoculated.—Aseptic wheat-seedlings were placed on moist filter-paper in sterile Petri-dishes and were inoculated in their basal region in three ways: by placing upon them (1) wheat tissue rotted by H. No. 1 (pure culture), (2) conidia of this organism, and (3) agar bearing an abundance of growing mycelium. No difference was observed in the effectiveness of the three modes of inoculation. Each gave a 100% infection, always visible with a hand lens in 2 days (Fig. 16) as a small spot, which could usually be seen at the same time without a glass. A longer time than two days was necessary to demonstrate that this spot would develop into a general rot, but so it did in all cases when the environment was favorable.

Seedlings in rag doll inoculated.—Wheat seedlings with shoots 2-3 cm. long were placed in a special form of rag doll (Pl. XXXIII) and inoculated with H. No. 1 by placing an oese of conidia-suspension on the base of each shoot without wounding. Infection was apparent to the naked eye in every case in two days, and the results in six days are shown in Pl. XXXIV. Rotting occurred in 6-12 days under favorable conditions. At 6 days the roots were often more or less blackened for long distances and the cortex filled with mycelium. Views of cross-sections showed a heavy infection of the second leaf, and the sheath completely occupied. With excessive moisture, seedlings were killed by the *Helminthosporium* in 6 days; but if in comparative dryness, only small lesions resulted. Seedlings similarly placed in rag-doll but atomized with conidia-suspension also gave 100% infection, and the infection was much more widely distributed.

Inoculation by diseased tissue or by fungus-bearing agar was in no way superior to inoculation with conidia.

Control, or check, rag-dolls, made in the same manner but without inoculum, at 2 and 6 days showed no lesions even under microscopic examination. In a very small number of cases there was infection by *Helminthosporium* in the checks, and in a few instances overgrowth by a *Helminthosporium* similar to H. No. 29, with geniculate conidia.

Roots of wheat inoculated.—Conidia of H. No. 1 were placed on the root-hairs of wheat-seedlings in rag doll. At the end of 4 days all roots so in-

oculated were yellowish or pale straw-color, as contrasted with the white, uninoculated roots, and they had scant root-hairs. Under the microscope



FIG. 16.—Lesions on unwounded wheat-seedlings two days after inoculation with conidia of H. No. 1. The shaded portion of the shoot was yellow to brown.

the cortical tissue was seen to be crowded with *Helminthosporium* mycelium coursing mainly in the longitudinal direction of the root. The mycelial threads within the root cortex were remarkably thick— 13μ . Wheat seedlings 2 cm. long, atomized with conidia suspension of H. No. 1, in 6 days were covered with infection spots over their whole surface.

Inoculations in soil.—Vials 12×70 mm., prepared as described on page 180, were used as containers. Wheat seeds were germinated aseptically, and when the shoot was about 2 cm. long they were inoculated and transferred to the soil in a vial. The results differed in no essential way from those described for the rag-doll inoculations, though the plant could be kept longer under observation since it was not solely dependent on the seed for food. Aseptic wheat-grains were also planted in these vials with the inoculum placed in three different positions: (a) on the seed; (b) 1.5 cm. above the seed; (c) 1.5 cm. below the seed. When on the seed, lesions occurred low; when above the seed, they were higher; when below the seed, no lesions were on the stem in early days but the roots were heavily infected.

Duplication, in pots and in benches, of all the above experiments made in vials gave identical results.

Recovery of Organism

After all the types of inoculation mentioned above, the organism used in the inoculation was clearly evident in the tissues and producing conidia upon them, and by dilution-plating it was recovered from them. During such recovery there was sometimes evidence of bacterial or other contamination, but in most cases of each type of inoculation no contamination occurred, and the pathogenic changes noted were clearly attributable to the fungus used in the inoculation.

INFECTION PHENOMENA ON WHEAT

Conidia of H. No. 1 and of H. No. 14 when placed on wheat in rag doll germinated from one or both ends as described elsewhere. The germ-tube grew rapidly, branching freely, and oriented itself lengthwise of the shoot more frequently than crosswise or obliquely, often following lengthwise the boundary between two wheat-cells. At certain places where this mycelium touched the wheat-surface it swelled slightly, producing a round or oblong *appressorium*. These appresoria sometimes, probably most often, arose by the simple swelling of a cell of the main thread (Fig. 17), though frequently also from short lateral branches (Fig. 17, d) or where the terminal

cell of a thread abutted against the wheat tissue (Fig. 17, *g*). So far as observed they differed from the usual mycelial cells only in shape. The appressoria are very numerous (Fig. 17, *b*). They are usually produced only after the mycelium has grown to considerable length; not, as is the case with some fungi, immediately on emergence from the conidium. In

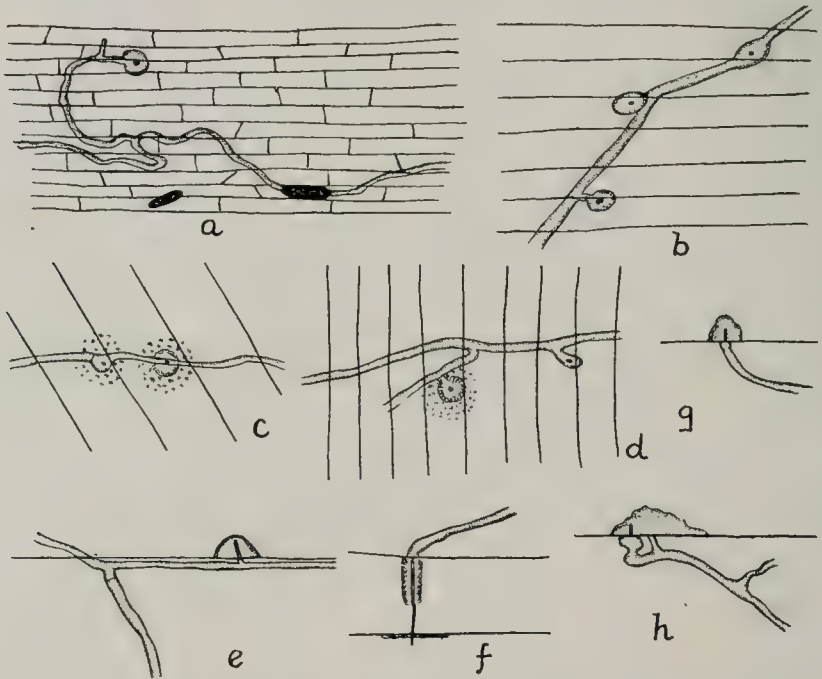


FIG. 17: *a*, H. No. 1 on wheat, 24 hours after inoculation, showing mycelium arising from a conidium, an appressorium, and penetrating mycelium; *b*, *c*, *d*, H. No. 14, showing appressoria, penetrating points, and "callus"; *e*, *f*, *g*, *h*, H. No. 1: *e*, mycelium within cell, and with a penetrating mycelium reaching into an adjacent cell, a "callus" there resulting; *f*, mycelium ending squarely against a cell-surface, penetrating it and then being covered by "callus", and eventually penetrating this and the next cell-wall, the latter being thickened; *g* and *h*, similar to *e*.

most cases the penetrating mycelium, viewed from above, appears as a minute bright point, or as if a minute hole had been pierced in the wheat cell-wall, much as is seen in the hyphopodia of *Meliola* (82) or on the appressoria of *Gloeosporium* (64) where penetration organs arise. Viewed laterally, the bright point of the appressorium is seen to mark the emergence of a haustorium-like strand which I shall continue to call the penetrating mycelium. This structure is much thinner than the usual mycelium (see Fig. 18) and of different staining reactions. It penetrates the wheat

cell-wall, and is sometimes simple, sometimes branched. At the place where the penetrating mycelium pierces a wall and enters a healthy wheat-cell there is developed, on the inside of the wheat-cell and surrounding and covering the penetrating mycelium, a callus-like structure (Fig. 17, *e-g*) which for brevity I shall term the "callus". As the penetrating mycelium continues to grow, the "callus" grows *pari passu*. Where many penetrating mycelia develop near each other this "callus" may become very large

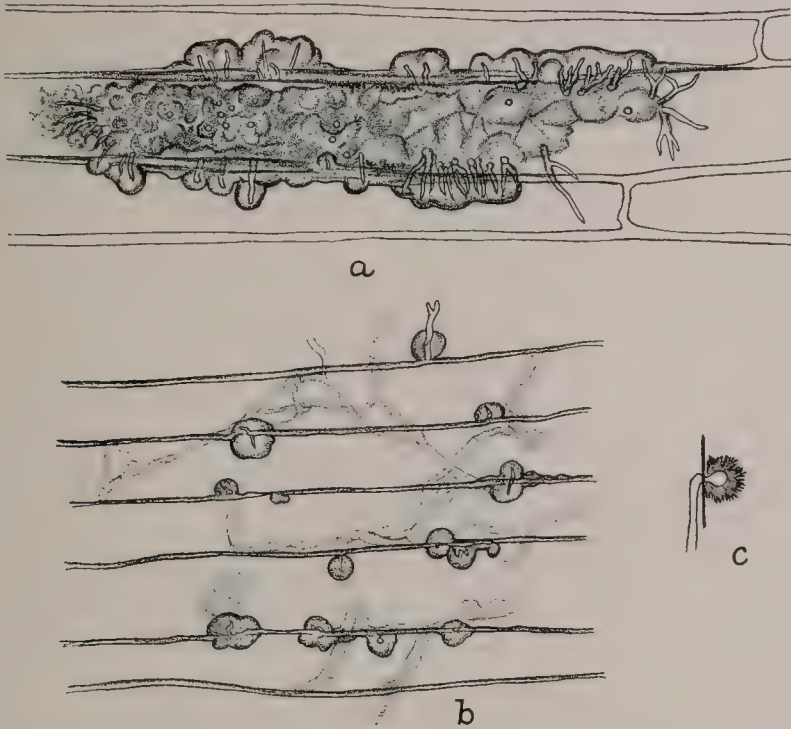


FIG. 18.—H. No. 1: *a*, large "callus"-formation, with many penetrating mycelia piercing the cell walls; *b*, mycelium spreading over the wheat surface, and at many contact points producing appressoria and penetrating mycelia; *c*, penetrating mycelium of unusual form, and the "callus" rough.

(Fig. 18, *a*) and complicated. The "callus" formation seems to be of the nature of a precipitation, probably resulting from toxic action, and a badly intoxicated cell can, in its protoplasmic disorganization, make numerous such deposits at points other than those of mycelial entrance. Thus in some instances the whole inner surface of a cell's walls may be thickly

studded with small dewy drops, apparently of precisely the same character as the "callus." (See Fig. 23, page 135.)

The host's cell-wall at and near the point of penetration, is markedly altered chemically, as is shown by various stain-reactions. Thus, adjacent to the point of infection several different regions giving different chemical reactions may be distinguished, as is indicated in Fig. 19. Region 3 gives the usual chlor-zinc-iodide reaction and stains like normal cellulose. None of the other regions do this. Region 4 stains darker with the usual

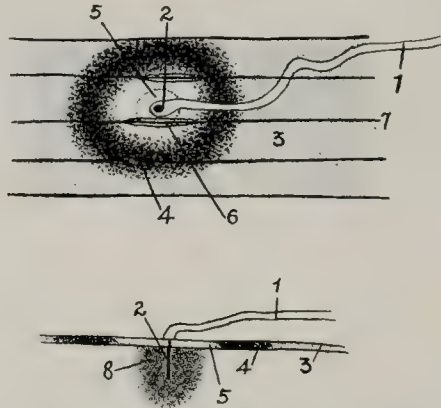


FIG. 19.—H. No. 1: regions of a young diseased spot: 1, mycelium; 2, penetrating mycelium; 3, normal wheat cell-wall; 4, region of darker staining; 5, region of lighter staining; 6, diseased inner lamella; 7, middle lamella; 8, "callus."

stains, but not so dark as normal cell-wall. The "callus" and penetrating mycelium stain faintly or not at all. The middle lamella stands out clearly in all of the diseased region, and on each side of it the inner lamella is seen to be thickened and of altered stain-reaction. Though penetration is sometimes directly through the wall it is much oftener into the middle lamella, and the mycelium shows a strong tendency to follow along the line of division between two cells, thus giving a gridiron effect to the mesh. This is possibly due to chemotropic attraction by the middle lamella or, possibly, because this is the weakest place in the cuticle. No case of stomatal entrance was observed; indeed, on the sheaths of "Golden Chaff" wheat stomata are seldom present.

Once within the host cell the mycelium grows rapidly, soon nearly or completely filling it (Fig. 20), and often forming a mass so dense that it resembles a pseudoparenchyma. Both longitudinal and transverse sections

show clearly that the mycelium is within, not between, the host cells. Penetration into adjoining live cells is attended by the same phenomena of penetrating mycelium, "callus" formation, and wall-changes, though appressoria were not observed in such cases, possibly on account of the difficulty of observation. Penetration into dead cells is not attended by these phenomena.

The chronological history of a lesion from a simple infection begins with the attack on one cell, which is soon overcome and occupied, and at 24, or, better, 48 hours after inoculation, observation with a 16 mm. objective shows regions with one to several cells diseased and browned,

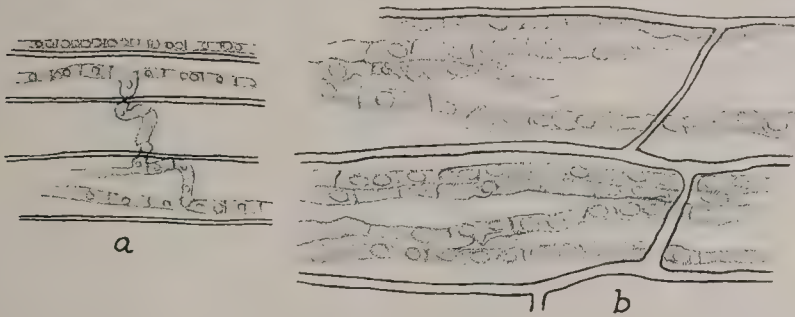


FIG. 20.—H. No. 1 on wheat: *a*, mycelium in cells and penetrating the side walls; *b*, mycelium running lengthwise within the wheat cells.

and the protoplasts undergoing disorganization and becoming browned. Owing to the length of the wheat-cells, the diseased regions are much longer than broad, and in many instances two diseased cells or two rows of them are seen with a quite healthy cell between them (Fig. 21). Under action of Javelle water the healthy cells plasmolyze beautifully, while the sick cells show no plasmolysis. Treated with acid fuchsin in glycerine, normal cells show no stain, while in diseased cells the entire protoplast becomes pink and the inner lamella, which is swollen, also stains pink. This softening and swelling of the lamellae was extensively studied by de Bary (8), Ward (123) and Büsgen (30). De Bary, who, in 1886, was first to separate a cytolytic enzyme from fungi (*Sclerotinia libertiana*), states that as the inner lamellae undergo partial dissolution they continue for a time to give the cellulose reaction, but eventually swell, disorganize, and lose this property (8, page 420). He also describes the fungus as growing in the middle lamella. Ward (123) describes the cellulose as swelling and softening under action of the enzyme produced by *Botrytis*. Here, too, the

mycelium grows in the middle lamella. Jones (71), working with *Bacillus carotovorus*, reports that the enzyme produced, attacks more strongly the middle lamella, but he noted also a softening and swelling of the inner lamella, but found that the cellulose stains (e. g., chlor-zinc-iodide) "give clear blue reactions with these fully softened walls." Van Hall (63), working with *Bacillus omnivorus* on Iris, reports a similar condition. The inner lamellae, swollen by *Helminthosporium*, no longer react as cellulose under this test. Blackman and Welsford (18), who describe in detail the entrance of *Botrytis cinerea* into bean leaves, state that neither before nor after penetration did the staining reactions of the cuticle give any evidence of its being softened or swollen or in any way altered chemically (though the subcuticular walls usually, if not always, swell), and no swelling

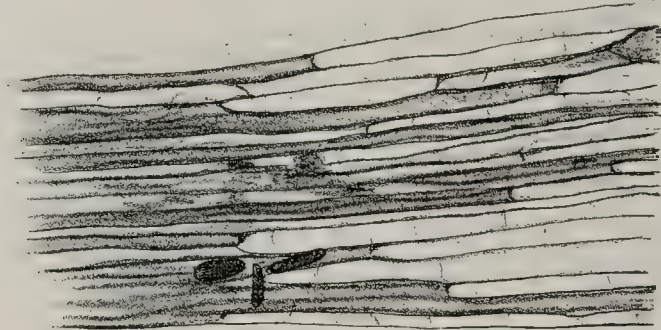


FIG. 21.—H. No. 1 on wheat shoots, second day after inoculation. Shaded portion was colored brown.

of the subcuticular cellulose was observed before the passage of the invading hypha through the cuticle. Pathogenic changes in the inner lamella precede those in the protoplast, that is, no toxin acts upon the protoplast prior to the swelling of the lamellae. The subcuticular layer swells. Penetration of the cuticle is by pressure. Gardner (58) mentions no changes occurring normally in staining reaction of host cellulose in leaves attacked by *Colletotrichum*, though in cases of delayed penetration he notes that the cell-wall under the appressorium retained safranin better than did normal cell-walls. In fruit penetration, however, he found that, characteristically, the inner lamella was so altered as to retain safranin. The action appears to be different in both quality and quantity from that described by Newcomb (86), who, studying enzymes in seeds, states that "with all the ferments the walls at first become hyaline, appear

gradually more transparent and finally 'melt away.' " In *Colletotrichum* Gardner (58) found the fungus similarly seeking the "depressions bounding the epidermal cells." This place of entrance is characteristic of many fungi—see Büsgen (30), Behrens (15), Ward (123), Noack (87), Miyoshi (83), Nordhausen (88), Schellenberg (99), and Aderhold (1). The last three named, believe this to be due to chemotaxic influences. Noack in describing the entrance of *H. gramineum* into the host mentions the appressoria. Similar structures have also been described in the anthracnose fungi by Hasselbring (64) and by Gardner (58), the pore in these structures being such as I find in *Helminthosporium*, though the appressorium in the anthracnose fungi is a mere swelling and is hyaline. Similar extreme narrowness of the mycelium at the actual point of penetration of host-walls is shown

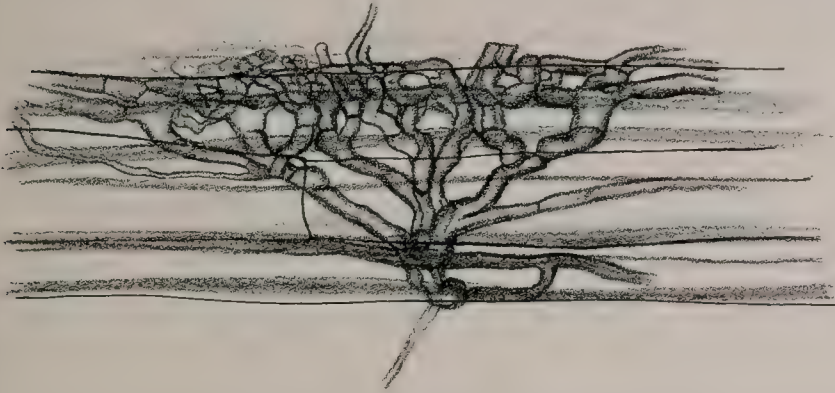


FIG. 22.—*H. No. 14* on wheat, showing fan-like mode of branching, see p. 105.

also by Ward (123, fig. 57), Gardner (58, page 27), Hasselbring (64), Büsgen (30), and Noack (87). Bakke (6) says of *H. teres* that the mycelium "penetrated the epidermis directly and made its way through the intercellular spaces," but he gives no further details.

Conditions very closely resembling the "callus" formation are figured by Dastur (41, figs. 8, 9), depicting the entrance of smut into sugarcane. This appears to have occurred only occasionally, and Dastur regards the "callus" ("plug") as probably a means of preventing infection. Conditions somewhat resembling that of the "callus" formation are described and figured by Wolff (128, figs. 2, 3) and by Brefeld (25, fig. 2) in the penetration of smuts into cereal tissue. Wolff (128, p. 20) describing this says: "Es tritt hierbei der eigenthümliche Umstand ein,

dass der Faden, sobald seine Spitze in das Innere der Zelle tritt, nicht frei in dieses hineinwächst, sondern von den inneren Schichten der Zellwand, welche sich gleichsam aus stülpen, wie in eine Scheide von bald grösserer bald geringerer, oft sehr beträchtlicher Stärke eingeschlossen wird und in dieser bis zur nächsten Zellwand weiter wächst." Brefeld describes very similar conditions, including much thickening which is of yellow color, but instead of interpreting it as an enclosing sheath he regards it as wholly due to thickening of the walls of the mycelium itself. He moreover states that this phenomenon is indicative of conditions in the host, as too great age, that are unsuitable to infection, and that it is not in evidence when the host is in fully susceptible condition. Whichever may be the true interpretation in the case of cereal smuts, I am convinced that in case of *Helminthosporium* the "callus" is produced by

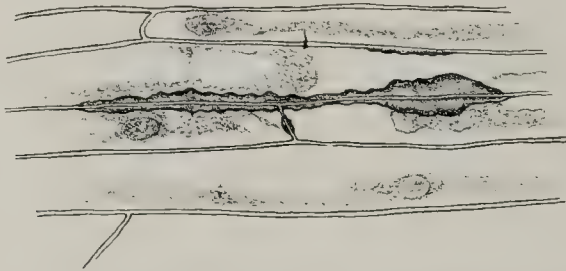


FIG. 23.—Infection by H. No. 1, 24 hours after inoculation, showing thickening of the wheat cell-walls by deposition on their inner surfaces. (Text citation at top of p. 131.)

the wheat-cell, and is not part of the mycelium. Ravn (91), describing the reactions to the intercellular mycelium of *Helminthosporium* in cereals, states that a thickening appears upon the cell-wall of the host, resembling a drop segregated from the cell, and that several such thickenings may be seen upon one cell, sometimes filling the intercellular spaces completely. They seem to differ from those that I describe (Fig. 17), however, in position, since they are without, not within, the cell, and in composition, as those noted by Ravn take aniline stains readily.

Ravn (91, fig. 23) describes an appressorium very much like that which I find and states that the mycelium from it enters the epidermal cell, where it so increases that it may fill the cell; then makes its way to the intercellular spaces and grows there exclusively, never again entering any of the cells even by means of haustoria. It therefore appears from his statements and figures that the *Helminthosporiums* with which he

worked, differed in a very fundamental way, as pathogenes, from those which I am studying, his forms being intracellular (except as regards the first cell invaded), and not at once killing the adjacent cells. That is, the condition pictured is much like that presented by Albugo, Peronospora, Puccinia, etc., except for the absence of haustoria. The forms with which I deal, on the other hand, though they enter through the middle lamellae, immediately become intracellular and at once kill the protoplast of the invaded cell, and proceed similarly with other cells. These differing-conditions, if substantiated by further study, probably indicate fundamental differences in the fungi in regard to their production of toxins or enzymes, and certainly indicate an entirely different type of pathogenicity. In these early stages the disease is properly a spot and not a rot. Whether it will develop into a true, general rot depends upon conditions. Phenomena like those described under the present heading, though differing in detail, were noted with H. Nos. 6, 8, 9, 14, 21, 36, 39, 40, and 41.

Action of various strains of Helminthosporium on wheat shoots.—Tests in rag doll, at medium moisture, with H. No. 1 and H. No. 3 gave at 2 days 100% infection for both; at 6 days there was no appreciable difference between the two; while at 10 days all shoots were rotten under H. No. 1 and some, but not so many, under H. No. 3. The test was repeated with 14 strains of Helminthosporium. All strains at 2 days showed 100% infection; the controls, no infection. The infection phenomena with all of these strains were all of the character described on pages 128, 129, showing penetrating mycelium, "callus," etc. At 6 days H. Nos. 1, 4, 5, 8, 13-16, 20, and 21 had all produced some rot. The roots also were distinctly yellowed by H. Nos. 15 and 16, while H. No. 20 showed less rotting than the other numbers mentioned above. H. Nos. 29 and 39 produced no rotting, and the lesions were visible only through a lens, but thus viewed, showed 100% infection, as indicated by the usual infection phenomena. H. Nos. 3, 6, 9, 17, and 18 remained local, as at 2 days. H. No. 29, a Helminthosporium with geniculate conidia, germinated abundantly from both ends of the conidium, and on wheat produced many penetrating mycelia and an abundant mycelium within the host, though the mycelial invasion reached only a few cells, and while extending for a considerable distance lengthwise, made but little progress laterally. The appressoria were usually pyriform, as was also the penetrating mycelium, differing thus from H. No. 1 (Fig. 17). Similar tests were made with three saltants, M6, M8, and M38. Notes at 2 days showed 100% infection, and at 6 days much rot by M6, and considerable rot by the other two.

Though infection can be determined with certainty, I have as yet no means of accurately measuring rotting power, or of determining whether differences noted in rotting are due to environment, host, or fungus. It seems clear, however, that *H. No. 29* is capable of causing only local spotting; and that the other numbers, perhaps even the "saltants," vary somewhat among themselves in rotting capacity, most of them causing rotting to some extent under favoring conditions.

The fact that so many and diverse races of *Helminthosporium* are able to cause rot of wheat, led me to test the ability of *Alternaria* to parasitize wheat seedlings. An *Alternaria*, found commonly on wheat seed, was isolated and inoculation made in rag doll on wheat seedlings. At 24 hours many wheat cells showed diseased spots, being in every way like those described on pages 128, 129, including the swollen middle and inner lamellae, browning of the cell-contents, and formation of the "callus" and penetrating mycelium. The *Alternaria* mycelium crossing several middle lamellae, usually produced an appressorium and penetration at each middle lamella. The *Alternaria* mycelium was also seen to enter the wheat-cells, killing a few of them, but in no instance was this fungus observed to cause rotting or to produce a spot large enough to be visible to the naked eye. It was seen, however, to penetrate the cells of the root cortex quite extensively, causing a slight browning. *Sterigmatocystis*, *Penicillium*, and several other fungi supposed to be mere saprophytes, were treated in similar manner, but produced none of the phenomena of infection.

SUSCEPTIBILITY OF VARIOUS HOSTS TO INFECTION

Tests in rag doll with H. No. 1

Corn.—Three seedlings showed no infection at 2 days, though conidia were present and had germinated. At 6 days all three plants were infected, the infection being confined to one or two cells, though the mycelium was clearly evident in these. Pammel, King, and Bakke (90) report negative results regarding infection trials of *H. sativum* on corn, but their tests were limited to leaves.

Barley.—At two days one plant was slightly infected, showing several lesions. In these the mycelium was abundant within the cells. Eight were not infected. At 6 days the infection showed no further progress.

Rye.—At two days three plants were infected; six not infected. At 6 days the infection showed no progress. The mycelium was observed within the cells and infection phenomena were as on wheat.

Sorghum (Holcus sp.).—There was 100% infection of both roots and stems, with pronounced rot. The same phenomena were observed as on wheat, including the appressoria, penetrating mycelium, and "callus." The sap of the infected cells was strongly tinged with red, and the "callus" and appressorium were deep red. Adjacent colorless walls soon became swollen and reddened. The red coloring-matter is absorbed by the nucleus, which becomes as brilliantly colored as by an aniline dye. At six days the shoots and roots were heavily infected, the diseased regions assuming a deep red, almost black, color, and conidia formed abundantly over the lesions. When such specimens were placed in alcohol, the red color diffused to the alcohol, coloring it strongly. This red coloration by the host is a response common on invasion of either bacteria or fungi on the sorghums and sugar-cane, and on corn in the case of some diseases.

Sudan grass (Holcus sorghum sudanensis).—At ten days 1 seedling gave positive and 5 gave negative results; at six days, 5 positive and 4 negative. Infection was slight on a few cells, but the mycelium was evident within the cells, and infection phenomena as on wheat were observed.

Common millet (Chaetochloa italica).—At two days 10 gave positive results. At six days the rot was progressing into the roots faster than into the stem, though black spots 3—4 cm. long were apparent. Infection phenomena were observed as on wheat, and much mycelium was seen within the tissue.

German millet (Chaetochloa italica germanica).—The results were practically the same as with common millet.

Amber cane (Holcus sorghum).—Results were much as on sorghum.

Red top (Agrostis palustris).—No phenomena of infection were observed.

Beans.—No rot was produced, no "callus", nor any other of the usual signs of infection; nor was it certainly determined that the mycelium entered the host-cells, though it seems probable that the fungus killed some of the bean cells.

Inoculation of leaves.—Pots of well-established seedlings of wheat, oats, rye, barley, corn, German and common millet, and sorghum were placed in a humid atmosphere (above 90% relative humidity) and atomized with suspension of H. No. 1 conidia. Well-defined spots occurred frequently on barley, less frequently on wheat. Leaf-spots due to a *Helminthosporium*, apparently H. No. 1, also occurred naturally on wheat in the greenhouse. Such spots were first pale; later with a mummified dark center surrounded by a pale zone; and were oval in outline. In rye the mycelium was seen to be abundant within the cells, and complete death

of the affected leaf, and also rotting without spotting, resulted. On the leaves in the humid air of the rag doll occasional spontaneous infections were noticed. In such cases the infection rapidly spread, involving nearly all of the leaf, which first turned pale, then very slightly brown. Aerial mycelium and conidia were profuse over the diseased portion.

SUMMARY CONCERNING ETIOLOGY OF FOOT-ROT

The evidence is conclusive that *Helminthosporium* is the cause of the basal rot of the wheat-stems. It is the only parasite constantly present, and has been repeatedly, and by many methods, proved capable of causing such rot. This conclusion is in accord with the findings of Beckwith (14), who as early as 1911 showed that *Helminthosporium* is a very common parasite within the tissue of wheat-plants. Bakke (6) in 1912 reported that when conidia of *H. teres* were placed on barley seeds, "At the end of two weeks' time there were not over seven seedlings to the row [originally there were twenty-five]. The roots were not in any sense indicative of a healthy state of growth." Oats and fescue-grass were not susceptible. A seedling blight of wheat observed since 1910 has been described by Stakman (113) in Minnesota, where in 1918-19 it became seriously injurious. The symptoms include dwarfing, foot-rot, and root-rot. The disease appears to be closely like, if not quite identical with, the one which is the subject of this paper. She proves conclusively that the cause is a *Helminthosporium*. A foot-rot of wheat due to a *Helminthosporium* having quite different morphological characters is also known in Sudan (see No. 46, page 184).

Certain of Ravn's experiments (91) conducted by inoculating seeds on wet filter-paper in a Petri dish, gave conditions much like those in the rag dolls. He makes no mention, however, of infection of the sheath nor of the occurrence of rotting of the basal region.

II. Evidence and Discussion of the Occurrence of Saltation within the Genus *Helminthosporium*

INTRODUCTORY

Early in my study of this *Helminthosporium* of foot-rot of wheat (herein designated as H. No. 1) it was noted that occasionally certain sectors of a colony growing on an agar plate differed more or less from the rest of the colony (Pl. XXII, 5; Pl. XXIII, 1). This phenomenon is of rather common occurrence in work involving Petri-dish cultures of either fungi or bacteria, and little significance was at first attached to it; but later, when

the frequent recurrence of these variant sectors commanded attention, transfers were made from several of them to freshly poured agar-plates, and a transfer from the normal portion of the colony was added to each of these plates at a distance of about 2 cm. from the other transfer. The variant transfer was then marked on the bottom of the doubly occupied plate as M (indicating mutant), and the normal transfer as O (indicating original). In all the early transfers the M transfer resulted in a colony (M1) of decidedly slower growth and more profuse conidial production than that produced by the O transfer. The two colonies also differed markedly in general appearance owing to minute single differences which were often difficult to analyze, but which in the aggregate constituted distinctions which were so well-marked and obvious that at first sight one would say that the two colonies were those of two distinct fungi (Pl. XXIII, lower fig.; Pl. XXVII). When these colonies grew to fill, or nearly to fill, the plate, transfers from them were made to new agar plates, and later, transfers from these second plates, and so on, the series of transfers being a long one. It was found that the differences appearing in the M1 and O1 colonies were usually maintained on succeeding plates. These findings led to the tentative assumption that forms in the variant sectors were mutants or saltants of a more or less permanent nature, and a more serious study of this phenomenon was undertaken.

In their origin the variants or saltants always appear as sectors which differ from the portion of the parent colony adjacent to them (see Pl. XXII—XXV). To the naked eye the most common deviations from the original type are in density, color, and rate of growth. Closer observation, with the microscope, frequently shows variation in the grouping, size, and shape of the conidia, and in the branching of the mycelium. Quite often many small sectors of divergent character appear at the edge of a large colony, especially on a plate that is beginning to dry. Many of these divergencies are merely modifications due to local environmental changes, and whether they are more can be determined only by close study of their behavior in subsequent transfer or transfers. Closer consideration of the characters involved in these saltations is best deferred to the following topic.

In following this discussion it must be borne in mind that M refers to the variant sector on the plate on which it originated; M1, to the colony resulting from the first transfer from M; M-2, to that resulting from the first transfer from M1, and so on; and that O refers to the original colony in which the M arose. It is my custom to give the saltant a serial number (writing this on the plate in which it was found), and, usually, to transfer

both the saltant and the original to the same plate so that they may have the same environmental conditions, the identical quantity and quality of agar, and by growing close together may render comparison easy. Notes on the origin and subsequent behavior of the saltants were made under the serial number, and the transfers were designated by additional numbers. Thus, M98-7 refers to saltant No. 98, transfer 7.

CHARACTERS OF SALTANTS AS SHOWN IN TRANSFERS

General appearance.—The colonies of the saltant and of the original when grown on the same plate were usually so strikingly different in general appearance (Pl. XXII, XXIII) that a mere glance sufficed to give the impression that they were colonies of two different species. This difference in general appearance is, on analysis, referable to one or more of the individual differences mentioned below.

Rate of linear growth.—Frequently the saltant was of much slower growth than the original, resulting in an M colony of much less diameter than that of the O colony, being often less than half of it (see two examples: one given in Pl. XXII and one in Pl. XXIII). In some instances, however, the M colony grew faster than the O colony.

Conidial production.—Frequently the M colony, especially when slow-growing, was much more productive of conidia than the O colony, so much so as to give the colony a decidedly perceptible darker color. In several instances, however, the M colony was of the opposite character, producing few conidia or, in some cases, going to the extreme of appearing to produce none at all. Generally speaking, rate of linear growth was in inverse ratio to that of conidia-production; while those saltants that were pale and possessed much aerial mycelium were usually of rapid linear growth and low conidial production.

Conidial clusters.—Some saltants varied strikingly from each other and from the originals in the mean number of conidia borne per conidiophore.

Conidial length, breadth, septation, and shape.—These characters, as evidenced by casual observation or by a study of graphs and the data derived from them, are shown to be strikingly different in various saltants. For clearness I present in this connection records concerning only a few saltants, giving graphs and data for others later.

Graphs of *conidial length* of saltants M35, M36, and M40, those which show greatest deviation from originals in this regard, are given in Fig. P with the essential data. It is to be observed that the modes of M35 and

M40 are 57.8 and 64.6 μ respectively, far below the mode of the original, which was 81.6 μ . M36 shows less striking difference, but this is still marked. Comparison of the means shows those of M36 and M40 to be approximately 17 and 18 divisions (1 division = 3.4 μ), while the original was 23 divisions. In other words, the conidia of M36 were only about three fourths the length of the normal conidium of H. No. 1. Such differences as they appeared in the microscope are shown in Pl. XXVI. The difference in variability is also strikingly large.

Striking variation in *conidial breadth*, both relative and absolute, was observed. Graphs and data of the more pronounced cases are presented in Fig. Q and others are given later. In connection with Fig. Y (Graphs 114-138) are given summary data on the conidial length of saltants included in this study. It is to be noted (Graph 6A, Fig. B) that whereas the mode of the ordinary conidium stood at 20.4 μ and no conidia exceeded a thickness of 23.8 μ , the modal thickness of M8-7 (Graph 75, Fig. Q) is 23.8 μ , with many conidia 27.2 μ in thickness, one even 30.6 μ . Such differences between saltants and the parental form are presented to the eye in Pl. XXVI.

The *ratio of conidial length to conidial breadth* is perhaps still more striking than the mere variation in length. In such variants as M6 (Pl. XXVI, b) and M8, while increased greatly in thickness the conidia were at the same time absolutely shorter, thus emphasizing to the eye both differences. The ratio of length to breadth in H. No. 1 is as follows:

$$\frac{\text{mean length}}{\text{mean breadth}} = \frac{22.62 \pm .05}{6.03 \pm .04} = 3.74 \pm .03^*$$

while in a sample of one of its saltants this ratio is

$$\frac{\text{mean length}}{\text{mean breadth}} = \frac{20.67 \pm .22}{7.82 \pm .11} = 2.64 \pm .04^*$$

and in another sample of the same saltant it is

$$\frac{\text{mean length}}{\text{mean breadth}} = \frac{19.58 \pm .30}{7.30 \pm .06} = 2.67 \pm .05^*$$

$$E = \pm \left(\sqrt{\frac{\left(\frac{Ba}{a}\right)^2 + b^2}{A}} \right)$$

*Probable error was computed according to the above formula kindly furnished me by Dr. J. A. Detlefsen, where a = probable error of A; b = probable error of B; and E = probable error of $\frac{B}{A}$.

Variations in *septation* were also noted; thus in Fig. R, Graphs 79-82 are quite different from Graphs 83 and 84, while all of these are lower than the results gotten from H. No. 1 in Graph 35, Fig. J. I attach but little value, however, to these variations because they seem inconstant.

Variation in *conidial shape* is common, some saltants showing the sides more nearly parallel than others, and the conidium as a whole less elliptical or fusiform.

Variation in submerged mycelium.—Aside from rate of growth and variation in branching which resulted in changes in density of the colony, differences in the submerged mycelium were observable in but two cases, most strikingly so in M26. In this saltant certain hyphal threads near the edge of the colony appeared to be much more vigorous than their neighbors, becoming a trifle thicker, and lengthening with such rapidity as far to outstrip the others, reaching out as single strands to a considerable distance beyond the usually even frontier of the colony, beginning then a dense, bushy branching in all directions, reminding one of witches'-brooms in trees. Numerous outposts of this kind give a peculiar lumpy appearance to the colony as seen by the naked eye. This peculiar mode of branching was clearly to be seen in M26, where it originated, and was frequent throughout subsequent transfers. Instead of single threads reaching out in this way, the mycelium sometimes formed fascicles which would grow out rapidly into new territory without branching, then suddenly branch profusely, forming a dense brush. These two rare characters were striking in effect both to the naked eye and under the microscope. Nearly every transfer from M26 or its descendants gave colonies with very strikingly marked sectors, characterized essentially by abundant conidial production, and therefore dark in color. The other sectors bore few conidia, were pale, and being a trifle less rapid in growth they were usually crowded out (Pl. XXX, lower fig.). These characters were maintained through many transfers. (See Pl. XXXI.)

Variation in aerial mycelium.—Saltant sectors and their progeny often differed from the originals in the abundance and character of the aerial mycelium. In some cases it was so scant as to be unnoticeable; in other cases so abundant and floccose as to obscure from vision the colony beneath. In character it varied from loose and fluffy to "ropy," the latter term indicating a tendency of many mycelial strands to twine together (Fig. 5, *c*, p. 104). In other cases it collected in clumps, the process being attended by peculiar distortions (Fig. 6, *e*). In some saltants these clumps were abundant and aggregated; in others few and scattered (Pl.

XXII, XXIII). The occurrence of clumps of mycelium upon the surface of the cultures has been stressed by Ravn (91) as of taxonomic importance (cf. also with Pl. XI, XIII, XXIII (below), XXVIII). H. No. 13, in one small sector, showed eight white clumps; the balance of the plate, none. In transfer M71 the clumping character seemed lost, but the following transfers were pale in type. In other cases the clumping habit seemed to be fixed and characteristic (Pl. XXVIII).

Variability in colony color.—The color is mainly due to abundance or scarcity of conidia or to abundance or lack of aerial mycelium, or to both. The white aerial mycelium is practically without conidia. Transfers from sectors with much white, sterile aerial mycelium were not always constant in these characters, but in many instances they were so; for example, M72, derived from single conidium C1-1, and M78, derived from M26. Differences quite comparable with these were noted by Crabill (36).

Zonation was well marked in some saltants and almost entirely lacking in others (Pl. IX, 3, 4, 5, 20). Some saltants formed *sclerotia* abundantly though the originals did not do so. *Density of colony* also differed, some saltants producing colonies of much denser growth than others.

Variability.—Variability itself was a distinctive character in certain instances. Thus, while the original of any given saltant is usually fairly constant in its characters and only occasionally gives rise to saltants, one saltant, M26 (Pl. XXX, below; XXXI), was definitely characterized by the fact of its inconstancy (see page 143).

Many saltants were tested as to their infecting power and their rotting power, but no real difference in these respects was noticeable between the different saltants, or between the saltants and H. No. 1. Since many species of *Helminthosporium* can infect many cereals this power may be rather fundamental in the genus and thus not be so readily subject to saltation as are less fundamental characters. I have no means as yet to measure slight differences in either virulence or rotting power. It may be mentioned here that Ravn (91) states that culture upon dead substrata diminishes the virulence of *Helminthosporium*. Whether such diminution was permanent or merely a temporary modification he did not determine. Edgerton (51) reports that different races of *Glomerella* differ in virulence.

Correlation of characters in saltation.—Certain correlations of characters are noticeable; thus, colonies of slow linear growth were usually high in

conidial production and *vice versa*. Correlations observed are indicated as follows:

Slow linear growth $\longleftrightarrow$ high conidia-production
 Much aerial mycelium $\longrightarrow$ low conidia-production
 Pale colony $\longleftrightarrow$ rapid growth
 Thickening of conidia $\longrightarrow$ shortening of conidia
 Pale colony $\longrightarrow$ low conidia-production
 Clumping of mycelium $\longrightarrow$ low conidia-production

The differences in colony-color and growth-rapidity here noted, are much like those described by Edgerton (51) in *Glomerella* plus and minus strains. Crabill (36) notes also a correlation in that his minus strains were always of more rapid growth than the plus strains.

TENDENCIES IN SALTATION

Saltants showing very low conidia-production, verging on sterility, coupled with paleness of colony, occurred with the greatest frequency. A type with increased conidia-production and of slow growth was next in frequency. The latter of these types was the most frequently thrown during the early period of my work though it has been rare recently. On the other hand, the former type, which rarely appeared at first, is now the most common. A type characterized by thickness of conidium, as M6, M8, etc., has been frequent all the time. These three types were by far the most common, and may be said to show the three tendencies. Markedly short-conidia saltants were few, as were also clump-bearing types that possessed permanence. Strains that threw either of the two types first mentioned above were very likely to continue to throw similar types. The same may be said of clump-bearing types.

STABILITY OF THE SALTANTS

Many saltants have been tested in various ways to determine, to some degree, their constancy. Through numerous transfers on corn-meal agar the O colony and the M colony of many saltants have been carried side by side. Under such conditions, though the original may give rise to new saltations or the saltant may saltate further, the main portion of both the O and M colony, as a rule, maintains its characters.

It is manifestly impossible to test all the saltants to ascertain what their future behavior will be. All that can be done at present is to record certain observations concerning them. Several saltants possessing strongly distinctive characters have been repeatedly transferred and have maintained their characters through all of these transfers; and as far as can be foreseen

are as stable in their present form as are other fungi. Thus, saltants with short conidia (as M35 and M40) and saltants with broad conidia (M6 and M8) have been cultured and graphs of conidia repeatedly made, the saltant maintaining its character. For example, a determination of measurements of conidia of M35—made after several transfers and the lapse of some weeks—gave the following data:

M	σ	CV
$17.31 \pm .25$	$2.51 \pm .17$	14.50 ± 1.05

Comparison of the above data with data of Graph 65, Fig. P, shows that this saltant not only remains far below H. No. 1 in length but is also constant. It is particularly to be noted that all comparative conidial measurements were made under standard conditions. Other characters exhibited by saltants, such as color, zonation, and aerial mycelium, are similarly permanent when strongly marked. Saltants are, however, subject to further saltation and indeed in some instances are exceptionally liable to it, for example, M26. Not all suspected examples of saltation afforded by variant sectors proved to be permanent in character, and some lost their distinguishing marks after one or a few transfers. Such instability was not observed in cases of conidial length and breadth, or of pronounced pale colony-color, but was more commonly noted in cases of slight differences of aerial mycelium, slightly pale color of colony, clumping, etc. While all cultures were carried, for convenience, on corn-meal agar, and their differences were observed on this medium, all that were studied critically were passed through other media—autoclaved wheat-shoots and live-wheat—to determine whether such passage would alter the character of the saltant. The saltant characters were apparent on other media, as green-wheat agar or beef agar, though the general colony-character of both original and saltant was changed by the medium. After passage through these conditions, or through wheat, they were inoculated under standard conditions for all graphic comparisons. There is no evidence of alteration of the characters of the saltants by such procedure. In other words, the saltation is not a phenomenon associated with the medium and ended when the fungus gets back to its normal habitat.

STABILITY OF THE SALTANTS THROUGH THE CONIDIA

Dilution platings of conidia of well-marked saltants gave colonies all alike and with all the characters of the saltant, showing permanence of these characters through the conidia.

APPARENT REVERSIONS

In several instances where colony color, aerial mycelium, or partial sterility was the saltant character, small sectors of the colony were so changed as to resemble closely the originals, and as far as tests were applied could not be distinguished from them (Pl. XXXII); in no case, however, where true saltant character was proved by constancy through several transfers did the whole stock revert; what appeared as reversion was limited to occasional sectors of the colony, and in no case did such change occur in the entire margin of a colony.

SUPPOSITIOUS CAUSES OF THE VARIANT SECTORS

Several alternative suppositions other than that of saltation may be briefly discussed as possible causes of the variant sectors. The mycelium at a certain point may become weakened, or die, and the change in equilibrium resulting may cause the variant sector. Spores of another *Helminthosporium* or of some other organism may fall into the colony from the air, and the variant sector may represent merely a contamination. The inoculum used on a plate that shows saltation may have consisted of more than one strain or elementary species of *Helminthosporium*. The first supposition is open only to crude experimentation, while the second, if valid, implies a wonderful *Helminthosporium*-richness in the air of my laboratory as well as very faulty technique. Since saltation occurred after the fungus, H. No. 1, had been transferred many times by lifting a small bit of agar from the edge of a colony, the presumptive evidence that no mixture then existed is very strong. The following experiments bearing on these suggestions may, however, be worth recording.

Wounding.—A culture of H. No. 1 on corn-meal agar was allowed to grow to a diameter of about 4 cm. Then by means of a hot iridium wire the mycelium was killed at the points indicated in Pl. XXIX, above. In all cases the uninjured parts soon entirely outgrew the wounds, and the whole colony presented an entire, normal outer border with no evidences of saltation. In some instances a clear straight line extended from the point of wounding nearly to the edge of the colony. Evidently disturbance of equilibrium such as this did not cause saltation.

Mixed planting.—Acting on the knowledge that the saltants were frequently slow-growing, and thinking that possibly ordinary transfers might be mixtures of two or more races, of which the slower-growing one ordinarily remained masked, M8, a well-characterized saltant, was planted

on a corn-meal agar plate and allowed 24 hours to grow, by which time a vigorous mycelium had developed. A goodly quantity of conidia of H. No. 1 was then placed in the midst of this young but well-established M8 colony, but it remained uniform to full occupation of the plate, showing no saltations.

Implanting conidia of H. No. 1 in a partly developed colony of the same strain.—This experiment was conducted like that of wounding except that instead of using the hot wire conidia of H. No. 1 were implanted at the points indicated in Pl. XXIX, below. All implants within the colony grew sparingly and resulted in small clumps 1—2 mm. in diameter and highly sporiferous (Pl. XXX, above). Implants at the edge grew poorly, but those a few millimeters outside the colony became established and grew well, each implant developing as an independent colony and inhibiting advancement of the old colony, but bearing no resemblance to a saltant. In one case, however, such implants showed marked change in characters and are still under culture as saltants (M70, Pl. XXX, upper fig.), though efforts to produce other saltants in this manner were fruitless.

Implanting other Helminthosporiums.—In a way similar to that of the last experiment numerous other species or saltants (e.g. H. No. 2 and M6) were implanted in an H. No. 1 colony, and always with the result that the implant either failed utterly to establish itself or developed as an entirely independent colony that did not blend with the main colony, being in this unlike a saltant sector in character. If implants were put about 3 mm. beyond the tips of the advancing mycelium, the conidia were observed to germinate before the mycelium of the H. No. 1 colony arrived, but even such implants became entirely submerged and lost.

Two entirely distinct types of *Helminthosporium*, found intermingled on a single grain of wheat, were planted together—an oese of suspension of the mixed conidia—on an agar plate. The resulting colonies gave the two types of *Helminthosporium*, but did not give the sectors so characteristic of saltants.

Saltation not due to parasites.—The saltant sectors and their transfers often differed so strikingly from their originals, particularly when they bore few conidia and had much white aerial mycelium (see Pl. XXVII) as to suggest that perhaps the great difference was due to a parasite growing in the *Helminthosporium* colony. Close microscopic inspection of saltant sectors showed that there was only one type of mycelium present, that it was all indistinguishable from *Helminthosporium* mycelium, and

that no conidia indicating contamination were present, therefore, if the colony were parasitized it must be either by a mycelium like that of *Helminthosporium* and without conidia, or by some virus of unknown character. To test this possibility well-established colonies of H. No. 1 were inoculated with such striking saltants as M84. Transfers of M84 were also made to points near the circumference of the H. No. 1 colony. If M84 bore a parasite of any kind this parasite might be expected to invade and overgrow the H. No. 1 colony. This it did not do, but the two colonies halted a few millimeters apart in the manner characteristic of two *Helminthosporium* colonies. It is quite clear that the idea of colony parasitism is untenable in this connection.

Position of inoculum.—Since it was possible that the differing appearances presented by the various sectors might be due to the position of the mycelial strands in or on the agar, that is, on top of it, in it, or below it, tests were made in three ways: 1, by placing conidia in an oese of water on the surface of poured agar; 2, by similarly placing conidia, without water, in a shallow scratch made in the agar; 3, by so cutting the agar that a flap about a square centimeter could be lifted and inoculated on the lower side, that is, the side in contact with the glass, the flap being then put back in place. These three modes of inoculation resulted in colonies of indistinguishable character.

SALTATIONS FROM SINGLE CONIDIA

Eight separate pure cultures were made from single conidia. The eight colonies were under careful microscopic control from the time of planting the conidia, through germination, and until the colony was well developed, and it is certain that in each instance the colony was from a single conidium. These pure strains, all alike in colony character, were labeled C1, C2, C3, etc. Well-marked saltants appeared in four of them as follows:

C1.....	{	72	
	{	110	
C2.....	{	108	
	{	109.....	{ 119
	{	121.....122	{ 120
	{	128	

		68.....95
		114
		115
		116
C3.....	36.....	117
		111
		112
		113.....128a
	106	
	107.....125.....	{ 126
		{ 127
C5.....	37	

Thus, it will be seen that single conidium 3 gave rise to sixteen clearly defined saltants; C5, to one; C1, to two; and C2, to seven—demonstrating absolutely that these saltants were not due to impurity of cultures. Evidently the saltant sectors do not result from contaminations.

FREQUENCY OF SALTATION

It is impossible to give any mathematically accurate statement as to the frequency of saltation in *Helminthosporium*. One hundred and twenty-six variant sectors were selected, transferred, and more or less studied; and this number could easily have been doubled or trebled. It is not probable that all the forms in these sectors were truly saltants; doubtless some of them were mere modifications, but the number that were permanent in character is large. How many of these saltants agreed with each other in observable characters it is also impossible to say, but since they arose independently it may be that they do not often agree absolutely. The percentage of saltants, based on those theoretically possible, is, however, small even in races that are most actively saltating. Thus in a colony 5 cm. in diameter there are probably more than 5,000,000 cells, and theoretically it appears probable that saltation occurs in a single mycelial cell, or perhaps by the union of two cells, yet saltations occur with even less frequency than one to each 6-cm. colony, therefore less than once out of 5,000,000 possibilities. In this connection, though no direct comparison is possible, it may be noted that East (47) considers the occurrence of twelve inherent variations in observations made on 100,000 hills of more than 700 varieties of potatoes, that is, about 1:10,000, as an unexpectedly high rate

of frequency. In tobacco only one bud variant was noted in 200,000 plants. Benedict (16) regards the production of 50 new Boston ferns in fifteen years as rapid. East (46) notes that all of the asexual variations have been losses of characters.

The pedigrees of the various *Helminthosporium saltants* which I have studied are indicated in the following table:

PEDIGREE TABLE OF SALTANTS

H. No. 1...	{	65	{	52.....74
		59.....		
		53*, 56*, 57*, 58		
		60, 61		
		78		
		89*		
		90*		
		96		
		73.....		
		76		
		69		
		92		
		93		
		94		
		88		
		88a.....		
		88b		
		88c		
		88d		
H. No. 13.....	{	71	{	75
		15*.....		
		64*		
		32.....		
		79		
		62		
		63		
		130.....		
		132		
		131		
		77		
		122		
		134		
		135		
		80		
		118		
		123		
		124		
		1*, 6, 7, 8, 10, 12, 14, 16-19*, 20, 21*-25, 28-30*, 31*, 32*, 33*, 34*, 38*, 39, 41-48, 50, 51, 70*		

*Numbers followed by an asterisk are pictorially represented in the plates.

The apparent paucity of saltation in the strains other than H. No. 1 may be due in large part to the fact that these strains have been cultured to much less extent, though there is also evidence that H. No. 1 really is more actively saltating than are the other strains; indeed several strains, as H. No. 2 and H. No. 29, have given no evidence of saltation. Saltation seemed to be as frequent in cultures derived from single conidia as from other cultures.

SALTATIONS OCCURRED ON VARIOUS MEDIA

Saltation was not confined to corn-meal agar, but was seen to occur also on green-wheat agar and on washed agar. The discrepancy in conidial measurements on two shoots (one in plate *e* and one in *e'*, cited on p. 121) may have been due to saltation on the washed agar. H. No. 34 as well as H. No. 1 showed saltation under standard conditions, that is, on washed agar on which wheat shoots were laid. Several of the shoots bore only sterile, white aerial mycelium, while the others were black owing to the usual number of conidia. Repeated transfers demonstrated the permanence of these characters.

SALTATIONS AND MODIFICATIONS OCCURRING IN TEST-TUBE CULTURES

Certain cultures received from correspondents under the label *Helminthosporium* remained largely or quite devoid of conidia. The following are brief descriptions of such *Helminthosporiums*.

H. No. 11, of which graph of conidial length is given in Fig. S (cf. with Graph 42, Fig. K) and conidial-breadth in Graph 101, Fig. V, differed in general colony-characters from H. Nos. 1, 3, etc., but most markedly in that it remained for the most part without conidia. Conidial septation is given in Fig. T, Graph 87.

H. No. 12, which was received under the label "*H. gramineum* (?)" evidently had sometime borne conidia, but transfers to many media under many conditions gave me none in any case.

H. No. 17, also labeled *H. gramineum*, under standard conditions on wheat and corn usually produced mycelium with no conidia, though in one case one wheat shoot gave conidia, while five others in the same dish gave none. From this one shoot the conidial-length Graph 97 (Fig. U) was made.

It seems to me that the three cases just mentioned should be regarded as those of saltants which have outstripped their originals in the test-tube conditions, while the rare cases in which they do bear conidia, par-

ticularly in the case of H. No. 17, given above, are to be regarded as further saltation or as reversions. In all of these cases of sterile cultures the mycelium, so far as can be judged, is like that of *Helminthosporium*, but the colony-characters are altered in ways easily compatible with the changes following loss of conidia-producing power and consequent change in vegetative vigor. Ravn (91) mentions frequent sterility of cultures in connection with *Helminthosporium*.

H. No. 18, labeled *H. avenae*, gave conidia only once, on one wheat shoot, although numerous trials were made. Its case is almost exactly like that of H. No. 17. From the very few conidia, though inadequate, Graph 98 (Fig. U) was made.

H. No. 19, labeled "*H. gramineum*," rarely gave conidia under any conditions, though somewhat more freely than either of the two preceding numbers. (See Fig. U, Graph 99.)

H. Nos. 13 and 14, labeled *H. sativum*, and Nos. 15 and 16, labeled *H. teres*, are particularly interesting as showing variations in test-tube culture. H. No. 13 is a lineal descendant of H. No. 14 while H. No. 16 is a similar descendant of H. No. 15. Graphs of these four strains also are given in Fig. U (Nos. 93-96). It will be observed here that the differences between Nos. 15 and 16, which are separate cultures from the same original isolation, are greater than the differences between strains known to be quite distinct. Graphs of conidial breadth of H. Nos. 13, 14, 15, and 16 are given in Fig. V.

H. No. 20, labeled *H. teres*, appears to be an excellent example of saltation in test-tube culture. It was so markedly different from other cultures that during the several months in which I was ignorant of its origin I thought that here was a clear case of difference between the European and the American species. Subsequent word from Dr. Westerdijk advised me of the American origin of this strain, and that she had received it in 1914 from Bakke, isolated from barley. It thus seems that this culture from Dr. Westerdijk is a direct descendant of the culture on which Pammel, King, and Bakke based their description (90), and that it now differs markedly from that description as well as from a culture (H. No. 3) which I received from Dr. Bakke which was also taken from the same plots that gave the original culture and was regarded by Dr. Bakke as being identical with *H. sativum*. Among my notes made before I knew of the origin of the culture I find this memorandum: "H. No. 20 is quite distinct from all other forms in my cultures in its quite uniformly 6-septate conidium with its squarish middle cell. Its colony-characters

are also distinct." (See Pl. IX, No. 20.) Conidial length is given in Fig. U, Graph 100; breadth, in Fig. V, Graph 102; septation, in Fig. T, Graph 88. (See also photomicrographs of conidia in Pl. XXVI, *d*.) By comparing these graphs and data with those of H. No. 3 and H. No. 1 it will be seen that the conidia are quite short and a trifle thick. The coefficient of cylindricity—78 for subcylindrical conidia, 74 for the more elliptical ones—is the highest coefficient shown in any of my strains (cf. with page 119). It seems very probable, therefore, that either the culture was contaminated in Dr. Westerdijk's laboratory or the other culture in Dr. Bakke's hands; or that Dr. Bakke's description was erroneous or that one of the cultures was contaminated by me; or that the facts represent a real hereditary change in morphology during a long series of transfers—and I incline strongly to the last of these alternatives.

H. No. 23 showed what appears to be a modification rather than a saltation, in that in the original culture received from Miss Weniger there were many abnormal tri-pointed conidia (see page 101). It is suggested that a change somewhat like this, if permanent, may have given rise to the forms with unequal central cell, for example, to H. No. 29.

All of the above-mentioned examples appear to represent clear-cut cases of change in morphological character in test-tube culture. The only essential difference between these changes in test-tube culture and the saltation reported in Petri dishes is that in the cases of the Petri dish selection of the saltant was voluntary, while in making transfers from tube to tube the selection was accidental.

SALTATIONS IN NATURE

That changes do occur under my culture conditions renders it highly probable that they also occur in nature—in the fields. Thus a saltant strain may become established on one wheat plant, form large numbers of conidia, gain foothold in a region, and then enlarge this foothold, perhaps to cover large areas. That one strain may thus outgrow another has been shown by Crabill (36) and is evident in my own work (Pl. XXX, XXXI, lower figs.). The fact that so many strains of *Helminthosporium* differing slightly but distinctly from each other, yet agreeing closely in general, can readily be isolated from cereals, indicates that probably this also has naturally happened, and that in the fields we have today large numbers of races or strains of closely related forms derived more or less recently from a common parent stock. To test this hypothesis experimentally, in field or greenhouse, by inoculation with pure cultures, and later isolating organ-

isms to search for differences, does not seem a promising line of research because negative evidence would be valueless, while positive evidence would be obtained only most rarely, even though saltation is very common. Since, even in my most rapidly saltating strains, changes occur in only 1 out of 5,000,000 cells, and re-isolations from soils would give colonies from single conidia only, that is, from a small group of cells, the evidence of saltation by this method of investigation could reasonably be expected only once in several thousand platings.

NOTES CONCERNING SELECTED INDIVIDUAL SALTANTS

Unless otherwise noted the permanence of the saltant characters were tested by repeated transfers. Colony-characters were determined on corn-meal agar; measurements of conidia and other conidial characters, under standard conditions.

M1. Origin slightly zonated (Pl. XXIII, 1), few conidia. M1-1 grew faster than its origin; ratio, 6.5:8; characters maintained through several transfers.

M6-1. Much like M1, but with decided difference in conidial breadth (Graph 70, Fig. Q).

M8. Growth slow; conidia few, pale, and thick (Fig. Q); septa few. The squarish cells very striking; differences apparent also on green-wheat agar.

M12-3. Quite distinct in septation and breadth. As to conidial length, see Graph 121, Fig. Y, and data.

M17-3. A distinct variant in thickness, septation, and shape. As to conidial length, see Graph 138, Fig. Y, and data.

M26. (See page 143, and Pl. XXX and XXXI.)

M35. Characterized by its very short conidia (see page 141 and Pl. XXVI, c).

M36. Derived from a single-conidium culture; conidia thick.

M38. The colony had much aerial mycelium and was quite white, though a shade of black from the surface-agar showed through (Pl. XXVII). It continued through many transfers as a pale form with scant conidia.

M53. (Pl. XXX). Very different from its origin, being covered with much loose, white, aerial mycelium, rendering the whole colony white and fluffy in appearance, while the original colony was neither white nor fluffy.

M54 and M55. These also were two white, woolly colonies.

M56 (origin, Pl. XXX) and M60. These were from a dark fast-growing sector of M26 and maintained character.

M57 (Pl. XXX, below)—M61 were from pale, fluffy, slow-growing sectors of M26. M61 eventually split up into many pale and dark sectors.

M62. The colony grew faster than its origin, and bore but few conidia.

M64 (Pl. XXVII). The colony was entirely white and fluffy from much aerial mycelium. It originated as a pale sector in M15-1.

M65 and M68. These were much like M62, and maintained character through many transfers.

M70. This arose where two colonies of H. No. 1 had been implanted just outside the edge of a colony of H. No. 1 (Pl. XXX, upper fig.). Both these colonies were strikingly different from the original, with much white and fluffy aerial mycelium. Transfer from one of them showed the character permanent through several transfers (Pl. XXV), but whether this saltation was actually induced by the implanting or whether a saltant was unconsciously selected for implanting can not be told.

M72. Origin a most striking, fluffy, white, sterile sector. Characters transmitted.

M75. A non-clumpy sector from an original that bore many clumps. Grew faster than its original.

M78. Very loosely growing, stringy, white, few conidia. Character maintained, but the saltant soon threw many strongly contrasting light and dark sectors, which, however, did not show permanence after several transfers.

M79. Origin like M78, but character soon lost in transfers.

M80. Very fluffy and white and rapid-growing.

M81. Had a narrow (1 mm.) pink line parallel to the colony-edge and about 5 mm. from it. This line advanced, remaining narrow, as the colony grew.

M83. Originated on green-wheat agar as a black irregular sector of smooth surface, the remainder of the original having a fluffy surface.

M85 and M86. Two very fluffy white sectors. One of these maintained its individual character; the other did not.

M87. Whitish in its origin, and in succeeding transfers this character was intensified.

M88. Very fluffy and white; permanent through many transfers.

M88a. A pale sector, a transfer from which threw numerous variant sectors, some light, some dark.

M92. Originated in thin, sterile sectors (strands) which produced sclerotia at their outer ends. In transfers the colony bore many sclerotia.

M93. White and fluffy.

M94. Very pale and with many clumps.

M95. Rapid-growing, pale, with few conidia and many clumps.

Several sectors later reverted to an appearance like that of the original.

M101—M105 were all fluffy, with white aerial mycelium.

The discussion of the causal fungus of foot-rot has so far been based, for simplicity, upon H. No. 1. Other strains of a *Helminthosporium* of the same general type have been isolated from cases of foot-rot from Madison county and have been proved capable of causing foot-rot. For example, in the spring of 1920 five isolations from one lot of material were made. These I designate as H. No. 1a, H. No. 1b, H. No. 1c, H. No. 1d, and H. No. 1e. All of these, in colony character and morphology, agree closely with H. No. 1, but H. No. 1a, b, c, d, have graphs of conidial length as shown in Fig. W, while H. No. 1e differed materially. It is obvious that the first four may be considered as of one strain, the last, e, of another strain, both strains differing somewhat from H. No. 1. The conidial breadth of H. No. 1a was as follows:

f	M	σ	CV
13	$5.88 \pm .07$	$0.39 \pm .05$	$6.79 \pm .89$

Conidial septation of H. No. 1a, H. No. 1b, and H. No. 1c, is given in Figure X, Graphs 111-113.

GENERAL DISCUSSION OF SALTATION

The existing differences in definition and usage of the term mutation, as also our very limited knowledge of cytological conditions in the genus *Helminthosporium* and our ignorance as to whether it has sexual stages, have led me to select the term saltation for the variations here discussed.

The term mutant is defined by Dobell (43), following Wolf (127) and Baur (11), as follows: "By *mutation*, accordingly, I mean a permanent change—however small it may be—which takes place in a bacterium and is then transmitted to subsequent generations. The word does not imply anything concerning the magnitude of the change, its suddenness, or the manner of its acquisition. The term denotes a change in genetic constitution. All other changes which are impermanent—depending generally upon changes of the environment—and not hereditarily fixed, are called *modifications*. The word 'mutation' has been used with such different meanings by so many bacteriologists and others, that the foregoing statement seems called for." Brierley (28) defines a mutation as "a genotypic change in a pure line"; and Vaughan (121), as "Those changes in form or

function which persist through one or more generations after the cause of the alteration has ceased to operate."

Since the variations herein reported occur in structures purely vegetative and result from no intervening sexual act, they are in kind comparable with vegetative variation known elsewhere—bud variation, etc.—with the exception that since the mycelium, consisting of a single row of cells, is the seat or origin of the variations the case is morphologically simpler than where tissues are involved, as in bud variation. De Vries (122) classes bud variations in general with mutations in that they appear as clear-cut discontinuous variations. Many examples of vegetative variation have been studied extensively and reported upon under the terms mutation, saltation, sporting, etc. Cramer (37) gives a very complete summary of the known cases in 1907. East (46), Stout (120), Ghys (61) and Shamel, Scott, and Pomeroy (102, 103) give reports, with extended bibliographies, concerning bud variation in the potato, *Coleus*, *chrysanthemum*, and lemon among the phanerogams. The transmission of such variations in the potato has been carefully studied by East (47, 48, 49) with the general conclusion that these asexually appearing variations concern characters that Mendelize in sexual reproduction. In the Pteridophytes, Benedict (16) reports saltation in the Boston fern. Dobell (43) summarizes the evidence from some twenty-eight papers concerning variability among the bacteria, discussing them in two categories: (1) physiological mutations, that is, changes in power to produce ferments or pigments; and (2) morphological mutations. He closes the first part of his discussion as follows: "It seems legitimate to conclude from the foregoing facts that some races of bacteria are able permanently to acquire new characters under certain conditions." He considers only two cases of morphological mutation, citing the work of Barber (7), who produced a race of long bacteria by single-cell selection, and of Revis (94), who claims to have produced a new race of *Bacillus coli* by the use of malachite green. Both Laurent (76) and Le Poutre (77) conclude that by passage a harmless bacterial species may acquire real virulence. An extensive résumé of the question of mutation in the bacteria is also given by Baerthlein (5). Numerous variations of yeasts, both morphological and physiological, are reported by Guilliermond. (62).

The validity of the conclusion maintaining that there is mutation among the bacteria and yeasts has been attacked by Brierley (28) on the ground that the changes reported as mutations are merely due to segregation of organisms of aberrant type from an originally mixed popula-

tion. The very large mass of corroborating positive evidence, though really conclusive only when based on single-organism cultures, makes it extremely probable, to say the least, that such saltations or mutations do occur in these groups.

Among the Eumycetes several examples occur of what appears to be saltation. Edgerton (50) in 1908, writing of *Glomerella rufomaculans*, states that "of the more than thirty collections studied from over twenty hosts, with less than a half-dozen exceptions all gave at least slightly different characters. Even the two collections on apples from Missouri and Illinois did not give exactly the same characters, but the differences were slight. The two collections from apples in the north, however, gave entirely distinct characters from the more southern forms on the same host. The southern form, especially on sugar medium, was characterized by very rapid growth and a very dark greenish-black color of the substratum and aerial hyphae; while the northern form grew more slowly and had very little dark color. Generally in the latter the aerial hyphae were colored pink from the profuse development of conidia. Even the form on quince collected in New York did not give the same characters as the northern form on apple. The forms on orchid, *Coffea*, and *Sarracenia*, collected in the same greenhouse at the same time, were not exactly alike in culture media."

Other examples were given by Edgerton (50) in 1908 of what appears to be the same phenomenon as that under discussion here, but as there is no evidence that he worked with single-conidia cultures* his apparent variations may have been due—though it is highly improbable—to segregation of elementary species. His general conclusion follows: "The only explanation of the phenomenon is that one or more individuals of the original form changed quite suddenly their course of development under cultural conditions. It is undoubtedly a *Gloeosporium* of the *Glomerella* type, with the development of the perithecia considerably different from other known forms. Mutations, so far as is known by the writer, have not previously been recorded among fungi, but the form just described seems to be one without question."

Here, too, should be mentioned the plus and minus strains of *Glomerella* studied and reported on by Edgerton (51) from single-conidia cultures, though this may represent a differentiation of sexes rather than of races. He gives several citations which indicate that other workers have

*In a personal letter dated February 7, 1921, he writes regarding this as follows: "All of the cultures that I used in that work were obtained by the dilution plate method and presumably came from single spores."

studied these strains, and records the belief that the culture mentioned above "as a possible mutation was really the minus strain of the bitter-rot fungus."

In 1909 I reported with Dr. Hall (Stevens and Hall, 118) for the genus *Ascochyta* variant sectors in Petri-dish cultures quite like those reported in this paper; but since the study was not made from single-conidium isolations it is possible, though not probable, that I had merely a segregation of elementary species.

Shear and Wood (105) in 1913 reported that in cultures of *Glomerella* started from a single ascospore "an important variation or mutation suddenly occurred in the fourth generation and was transmitted through three following generations." They cite other variations, less permanent, which they regard as fluctuations.

Burgeff (31) in 1914 reported results from an extensive study of asexual variation in the genus *Phycomyces*. Working from single-spore isolations he got great diversity in many characters.

Crabill (36) in 1915 described two strains of *Coniothyrium pirinum* which he designated as plus and minus strains that differ markedly in several characters, particularly in size and abundance of pycnidia (verging on complete sterility), and in color of colony. He says:

"The cultural studies show that minus strains may arise from plus strains by a sudden sporting or mutation. An objection might be raised that these cultures were impure, i. e., mixtures of two strains. In anticipation of such an idea it seems desirable to state that frequent pourings of dilution cultures were used to preclude such a possibility. Progeny were then selected only from well-isolated plant, microscopic examination of which showed that each was derived from a single spore. . . . Both strains have repeatedly arisen from the progeny of a single plus spore. When once purified the minus strain remains constant from generation to generation. The variation is apparently occurring in only one direction. . . . The only explanation which remains is that the minus strain is a sport or mutant arising from the plus strain at irregular and unprognosticable intervals."

The plus strain by sudden sporting gives rise to the minus strain, but minus strains were not seen to give rise to plus strains, that is to say, the saltation is orthogenetic. He states also that the variation apparently occurs in the spore and not in the mycelium, which is quite the contrary to my findings. He finds, in agreement with my work, also with Kleb's law (74), that the minus strain, that is the sporiferous one, grows faster

than the plus strain. The sectoring and the colony differences which he pictures are much like those shown for *Helminthosporium* in this paper. He also adduces evidence to show that these plus and minus strains occur in nature and have been isolated by independent workers. He attempted in four ways to induce saltation artificially but met with no success. Crabill (35) has reported, in abstract, "a somewhat similar mutation in a fungus belonging apparently to the genus *Phyllosticta*." Blakeslee (21) reports: ". . . in 1912-13 I found numerous variants of various degrees of distinctness in the offspring of a single plant (*Mucor*) obtained by sowing non-sexual spores." Writing of *Mucor genevensis* he says (20): "In all, somewhat over 38,000 colonies from individual sporangiophores have been inspected and a relatively large number of variants of different degrees of distinctions have been obtained . . . the mutants tend eventually to revert to the normal type. Two, however, have seemed more stable." He concludes: "They add to the evidence, already obtained from other groups, that mutations are not restricted to processes involved in sexual reproduction."

Brierley (27, 28) reported an albino *Botrytis cinerea* which was a form with pale sclerotia though the parent form always had black sclerotia. This albino was observed to arise from a colony derived from a single conidium and from a race that had been under culture for considerable time, always producing black sclerotia. The purity of his culture seems to have been carefully guarded, and this case, though standing alone, would furnish positive evidence of the sudden occurrence of a hereditary difference in this fungus.

Dastur (40) in 1920 described saltations in *Gloeosporium piperatum* consisting in the absence or presence of perithecia, acervuli, or setae, and in the development of aerial mycelium. He says: "Thus all of a sudden the original sterile culture broke up into two different strains, one producing only perithecia on sterilized chilli stems and the other forming acervuli with and without setae." Some of these strains were not constant in character, but others persisted through many transfers. He states that great or sudden variations have never been observed from conidial strains, but that "in cultures made from perithecia of the strain of *Gloeosporium piperatum* incredibly large and often very sudden variations have been obtained." Burger (32) in 1921 reported mutation of several types in *Colletotrichum*, involving permanent changes in many characters. He found these occurring in cultures derived from single spores and showed that they were permanent through the spores. Jennings (70), who worked

with the shelled rhizopod *Diffugia*, states that most of the work on uniparental reproduction has yielded the result that during such reproduction the hereditary constitution (genotype) appears not to change though the organism may differ much in outward character. Many papers cited support this view though some are opposed. Jennings says with regard to his own results: "After many generations of descent from a single progenitor, such a single family . . . has differentiated into many hereditarily diverse stocks." These diverse stocks differ hereditarily not only with respect to particular single characters but also with respect to the combination of characters. Many individuals of uniparental reproduction have shown a marked permanence of hereditary character in single lines of descent, all the progeny being like the parent in hereditary constitution; and further, many such lines, diverse in hereditary constitution may exist in a population, and the effects of selection consist mainly, if not entirely, in the isolation of such diverse lines.

East sees no reason to believe bud variation different from germinal mutation and says that it may be progressive, digressive, or retrogressive. Bateson (10) holds that bud variations are due to qualitative cell-division in somatic tissues, giving somatic segregation of unit factors. East points out that in the large majority of cases of bud variation there has been simply the loss of a *dominant* character and hence the appearance of a related recessive character. In some cases there is absolute disappearance of the dominant character; in other cases it appears to be latent, and it may reappear. Variations in color constitute over 70% of all bud variation. Colony color in *Helminthosporium* is also a very common variable but this is, in all probability, entirely incomparable with color variation in flowering plants.

Brierley (28) holds, for *Botrytis*, that even if sexuality occurs, the fungus is "on all evidential criteria, an asexual homozygotic organism in which the isolation of a single spore strain necessarily implies the isolation of a 'pure line' ". . . . A genotypic change in a pure line is a mutation." Similarly, Shear and Wood (105) regard individuals originating from single spores of *Glomerella* as homozygous, though on reasoning differing somewhat from that of Brierley. Crabill (36) also holds that since his fungus "reproduces asexually segregation from heterozygous parents cannot explain the origin of the strains." Accepting Brierley's criteria, my *Helminthosporium* single-spore isolations are equally homozygotic. In at least three forms on cereals *Helminthosporium* is known to be the conidial stage of the ascigerous genus *Pleospora*. As ascigerous

stages are known in many cases to arise sexually, it may be expected that all perithecia represent sexual stages and a sexual act. The particular forms with which I am working, that is *H. No. 1* and derivatives, have given no evidence of perithecial formation nor is it actually known that they possess sexual stages. The presumption, however, is that they do, so it is quite possible that my culture of *H. No. 1* is derived from an ascospore, that is, may be the result of sexual parentage; and this sexual act may have occurred in the not distant past. This is all hypothetical but it appears to me to point to a possibility of an heterozygotic condition in *Helminthosporium*, as well as in *Glomerella* as reported by Shear and Wood (105) and in *Coniothyrium* as reported by Crabill (35), since so few generations may have elapsed since fertilization that the heterozygosis has not yet been eliminated. Such supposition in the case of *Botrytis* is less tenable.

It is suggestive to note here that Dastur (40) found variation a common phenomenon only in strains that were recently derived from perithecia; also that bud variation is more common in hybrids (East, 46). It is therefore thinkable that such of my strains of *Helminthosporium* as are saltating are of recent ascigerous origin, while others that are not saltating (for example *H. ravenelii* and *H. geniculatum*) are of distant ascigerous origin.

If heterozygosis be eliminated from the discussion two other possible explanations, suggested by Brierley regarding *Botrytis*, may be considered here, namely, that of nuclear transference during mycelial anastomosis (Fig. 5, p. 104) or that of cytoplasmic contamination by such anastomosis. Evidence on these questions, both from cytology of the mycelium and from knowledge of sexuality, is quite lacking. Accepting none of the above hypotheses, the saltation would be a mutation in the strictest sense of the term.

Reported mutations in *Aspergillus* and *Penicillium* described by Arcichovskij (2), Waterman (125), and Schiemann (100), and said to be induced by environmental changes, are quite extensively discussed by Brierley (28), who, repeating much of their work, concludes that when the fungi showing these changes are returned to their original environment they resume their original aspect; that in fact the changes were mere modifications due to environment.

The cases reported by Brierley, Burgeff, Blakeslee, and Crabill, and my own work reported herein, all based on single-spore culture and carried under observation for sufficient time to give assurance of permanence, constitute complete proof of the occurrence of the phenomenon of sud-

den change in character among the fungi. The evidence from Edgerton, Shear and Wood, and Dastur, while not so complete, is strong collaterally. It would seem from all this evidence that this phenomenon is common and widely distributed among the fungi, though unquestionably it is more common in some species and races than in others.

TAXONOMY

The classification of these *Helminthosporium* "forms," indeed of all the fungi imperfecti, presents unusual difficulties. That they are only "forms" of which we do not yet know the "perfect" stage, is no more relief from the necessity of classification than is incomplete knowledge adequate reason for delay in attempts to classify other plants. In the present instance some well-defined "species," in the old sense of the word, stand out—for example *H. ravenelii*—while, on the other hand, several of the strains of *Helminthosporium* in my collection differ in one or more slight ways yet agree with each other closely in general type. For example, my H. No. 1, H. No. 11 (isolated by Stakman from wheat in Minnesota), H. No. 13, isolated by Durrell in Iowa, H. No. 23, isolated by Weniger in North Dakota, and an unnumbered one isolated by Hoffer in Indiana, are all clearly the same general type of organism, and yet they differ from each other in minor particulars.

It is evident that we have in the genus *Helminthosporium* large numbers of races that vary consistently and constantly, though but slightly, from each other. These variations may be morphological in the usual sense of the term, or as shown in cultures, or as demonstrated biometrically. It is quite probable that here, too, there are, as elsewhere in the fungi, differences in virulence, and therefore in biologic relationship, and physiologically. Examples are numerous among the fungi where such comparatively minor differences are regarded as of specific rank and the new group is designated by a new binomial. There are also numerous examples where such slightly variant types are regarded as varieties or races of the species. These varieties or races have been variously designated as follows (or by the equivalents of these terms in other languages):

- Physiological species (Hitchcock and Carleton—67)
- Species sorores (Schroeter—101)
- Biologische Spezies (Klebahn—73)
- Biologische Arten (Rostrup—95)
- Schwester Arten (Schroeter)
- Biologische Rassen (Rostrup—95, 96)
- Specialiserte Formen (Eriksson)

Formae speciales (Eriksson—55)
 Gewohnheitsrassen (Magnus—80, 81)
 Races spécialisées (Marchal)
 Mikrospecies
 Biotypes
 Elementary species (de Vries)
 Pure lines (Johannsen)
 Biological forms
 Biological races

Fischer (56) adopts the practice of recognizing as distinct all forms which differ in their choice of hosts in so far as the hosts belong to different genera; a procedure that leaves the specific rank and name of the parasite subject to vicissitudes arising from subsequent changes in the conception of the taxonomy of the host. It is yearly becoming more evident that distinctions such as these are common in the fungi within what were previously regarded as groups of specific rank.

Biologic specialization in the rusts was announced in 1894 by Eriksson (55), and has since been abundantly attested by Stakman (109), Stakman and Piemeisel (111), Stakman, Piemeisel, and Levine (112), by Arthur (3, 4), and by others (57, 68). Abundant evidence that it occurs in the powdery mildews is afforded by Neger (85), Salmon (98), and Reed (92).

The first demonstrated cases in the fungi imperfecti were probably in *Helminthosporium*, reported by Ravn (91). It was demonstrated in *Septoria* by Beach (12). Reed (93), summarizing regarding biologic specialization, cites papers to show its occurrence in the following genera: *Synchytrium*, *Albugo*, *Peronospora*, *Taphrina*, *Claviceps*, *Dibotryon*, *Rhizisma*, and *Colletotrichum*.

Evidence that there is differentiation morphologically, slight but measurable and constant, has been found among the rusts by Arthur (3, 4) who, writing of *Uromyces* on *Spartina*, says that "the four races of this species exhibit not only physiological specialization but a certain amount of morphological differentiation." Similar findings are reported by Bisby (17) concerning *Puccinia epilobii-tetragoni*, by Stakman and Piemeisel (111) regarding *Puccinia graminis*, and by Arthur (3, 4) regarding *Dicaeoma poculiformis* on *Phleum*. Brierley (26) has demonstrated by single-spore cultures the existence of elementary species, morphologically distinct, within the species of *Botrytis*, *Penicillium*, and *Stysanus*. Gäumann (60) has shown *Peronospora parasitica* to consist of very numerous races separable on both biologic and morphologic grounds. Similar findings regarding *Plasmopara* are reported by Wartenweiler (124). *Pes-*

talozzia guepini was reported by Bartlett and La Rue (unpublished paper) to consist of numerous distinct strains. *Ascochyta chrysanthemi* was shown to consist of at least two distinct strains by Stevens and Hall (118). Crabill (34) states that there are four distinctly different types of *Phyllosticta pirina*, and that *Coniothyrium pirinum* (34) is similarly composed of distinct races. Burger (32) demonstrates a similar condition in the genus *Colletotrichum*. Wiedemann (126) has published species of *Penicillium* based on differences shown on culture media—a procedure very common in dealing with the bacteria. The wide-spread occurrence of slightly but constantly differing varieties within the species of fungi is apparent; also that two diametrically opposed methods of procedure are in vogue to meet the situation. One method gives specific rank to each elementary species, or race, or strain; the other restricts binomial designation to the larger groups (the collective species), recognizing that the latter consist of numerous smaller groups—the elementary species (or races or strains). Lotsy (79) suggests that the terms “Linneon”—defined as “a total of individuals which resemble one another more than they do any other individuals”—and the term “Jordanon”—for the elementary species—be employed. This suggestion, in that it recognizes the elementary species as properly in one category, and the group of elementary species as belonging in a larger category, both subordinate to the genus, is in accord with the general discussion of “Aspects of the Species Question” (29)—see particularly conclusions of Britton and remarks by Coulter. The difficulties regarding elementary species that beset the taxonomist in dealing with the flowering plants are manifoldly increased when the classification of the fungi imperfecti is in question. Thus in the genus *Septoria* there are more than 1200 named species usually delimited from each other by barely three or four characters, and these extremely variable. Many other genera present conditions equally bewildering. The result is that it is absolutely impossible, even with the type specimens in hand (and they are usually unobtainable), to determine species accurately. It is highly probable that many of the forms now listed as species in the fungi imperfecti are either identical or merely biologic races—that is elementary species. To designate each elementary species either in the fungi imperfecti or elsewhere by a binomial defeats the very purpose of the name and renders it not only useless but cumbersome. The conceptions of Lotsy and of Britton and Coulter as noted above, seem particularly applicable here and indicate the advisability of using a binomial to designate a group which shall comprise many elementary

species—a course that I have already followed in the case of *Colletotrichum* (115) and which was followed by Elliott (53) in dealing with *Alternaria*.

My H. No. 1, H. No. 1a, H. No. 1b, H. No. 1c, and H. No. 1d, the cause of foot-rot in Madison county, Ill., as well as my *Helminthosporium* numbers 3-9, 11-19, 22-27, 34, 37, 38, 42, and 43, all belong to the same general type and are characterized by a conidium that tapers toward each end from a point of greatest thickness which is nearer to the base than to the apex of the conidium. The conidia are therefore not typically cylindrical or even subcylindrical. While all of these numbers agree in general type, many of them differ somewhat from others in the collection. Thus Nos. 1 and 3 differ as is shown in Plates IX, XI-XIII, and, so far as observed, in this character only, and only under the conditions described. Others differ in modal spore-length or septation, in distinctness of zonation, or in other minor colony-characters (Pl. IX). Number 13 differs slightly even from No. 14, though both are derivatives from the same original culture; and the same may be said of Nos. 15 and 16. These differences which now actually exist, are probably due to unconscious selection of saltants in transferring from tube to tube. All of the numbers listed above which show constant, though but slight, differences from other numbers I regard as elementary species, the Jordanons of Lotsy. They need not be further characterized or differentiated than has been done in previous pages. One of these elementary species, H. No. 3, is derived from an Iowa culture probably identical in character with that from which Pammel, King, and Bakke described *H. sativum*, and this culture, No. 3, still agrees essentially with their description. All of this group of elementary species may therefore be regarded as belonging to the *Helminthosporium sativum* group, or Linneon. The question of the possible identity of this group with the *H. teres* and *H. sorokinianum* groups I shall not now discuss further than to point out that so far as can be judged from the picture of *H. sorokinianum* given by Sorokin (107) that species is not characterized by longitudinally eccentric conidia; also that subsequent to the publication of the species *H. sativum*, Bakke (6) states that "cultural experiments have determined that the disease is due to *Helminthosporium teres* Sacc." He adds: "He [Dr. Ravn] further substantiated my opinion that the disease was due to *H. teres* and similar to what had been so prevalent in Denmark during the years 1898 and 1899." Bakke, in a foot-note, however, adds: "A. G. Johnson, of Madison, Wisconsin, considers *H. sativum* and *H. teres* distinct forms." Saccardo, who examined *H. sativum*, sent to him by Bakke, expressed the

opinion that the disease was due to *Helminthosporium teres*. It may be remarked here that Ravn (91) says that leaves are the only substrata on which conidia are developed; which is certainly a marked distinction from the *H. sativum* group which sporulate so freely on agar of many kinds.

There is no question whatever in my mind that by means of biometry and a study of biologic relations and cultural characters, tenable distinctive diagnoses can be drawn up for many races of *Helminthosporium* on the five leading cereals. How many of these should be designated by binomials and how many left unnamed appears, on final analysis, to be a question of the utility of such naming, which, in turn, may hinge upon their economic or other importance rather than upon the magnitude of their morphological or other differences.

H. No. 20 is particularly interesting in that it is—if no error exists in its history—an example of saltation so great as to remove the organism entirely from the group under discussion (the forms with tapering conidia), and consequently to place it in a group (Linneon) different from that to which its known relatives (H. Nos. 13 and 14) belong.

CONCLUSION

The present study was undertaken with two leading objects: (1) to determine the efficient cause of the rotting at the lower part of the wheat stem; and (2) to throw light on questions of morphology and parasitology in the genus *Helminthosporium*. The questions arising from saltation injected an additional interesting series of observations. The evidence is complete that *Helminthosporium* can and does cause foot-rot at the base of wheat stems. The study has also shown the *Helminthosporium* (H. No. 1) to be a root parasite. This phase of the disease has been studied only incidentally, but it is worthy of searching investigation since it may lead to the rosetting often associated with foot-rot, and thus predispose the plant to foot-rot.

SUMMARY

1. In the rotting base of the wheat a *Helminthosporium* is the only organism constantly present (p. 124).
2. The culture characters of this fungus were studied on many media (p. 79) and under many and various environmental conditions. Slight changes of nutriment, as afforded by small differences in agar formulae or by the temperature at which the agar was made, produced marked effect on growth-characters. Of many agars tried, corn-meal agar proved most useful. Cereal shoots autoclaved, served as a still more favorable medium.

3. Morphological characters are largely altered by environment. Quantity as well as quality of food produces change in characters. Humidity has an important influence on the production of conidia, on the aerial mycelium, and on sclerotial formation (p. 93), influencing even conidia length (p. 95).

4. The optimum temperature for growth is about 25° (p. 98).

5. Carbohydrates in the medium favor production of a dark color (p. 100).

6. Marked effect of nutrition conditions on conidial length, septation, and shape was noted.

7. From the above findings it follows that collections to be comparable must be made under similar conditions as regards the factors mentioned (p. 102).

8. A procedure to secure standard conditions for study of the fungus was devised (p. 180).

9. The mycelium, aerial and submerged, is described. The cells bear several nuclei. The senescent mycelium undergoes autodigestion (p. 108).

10. Conidia show distinct basal and apical markings. The wall is in two layers: the outer (episporium), thin and brittle; the inner (endospodium), thick and gelatinous (p. 111).

11. Germination is usually terminal; anastomosis of germ-tubes is common (p. 115).

12. The conidia are thickest at a point between the base of the conidium and its middle point. The concepts "coefficient of longitudinal eccentricity" and "coefficient of cylindricity" are introduced for purposes of more accurate description (pp. 117-120).

13. Conidial length, breadth, and septation are studied biometrically.

14. For comparison, a biometric study was made of *H. ravenelii* (p. 121).

15. The etiological relation of the *Helminthosporium* (H. No. 1) to foot-rot was demonstrated by its constant presence, by the absence of other parasites, and by its proved ability to cause infection and rotting under various conditions, as by inoculation of seedlings in Petri dishes, in rag doll, and in soil (pp. 124-128). The fungus was shown to enter cells of leaf-sheath, stem, and root.

16. A study of the infection phenomena shows important changes in the cell-walls of the host; and the development of appresoria and a callus-like formation (p. 128).

17. Many strains of *Helminthosporium*, some very different morphologically from others, can produce some or all of the phenomena of infection (p. 136).

18. *Alternaria* produces some of the marks of infection, including the changes in the host-cell, the "callus," and entrance into the host-cell. *Penicillium* can not do this (p. 137).

19. Wheat, corn, barley, rye, sorghum, Sudan-grass, and millet are more or less susceptible to rot by *Helminthosporium*.

20. Saltation, possibly mutation, is common in certain races of *Helminthosporium* (p. 139).

21. Saltation is evidenced in general colony-character; rate of growth; conidial production; conidial clusters; conidial length, breadth, septation, and shape; mycelial characters, color, zonation, and sclerotial formation (pp. 141-144).

22. Certain saltants differed so markedly from their parent as to far exceed the usually accepted specific limits (p. 141).

23. Certain correlations and tendencies of characters in saltation were noted (pp. 144-145).

24. The saltants were, in the main, permanent in character (p. 145).

25. They were permanent through the conidia (p. 146).

26. What appeared to be reversions sometimes occurred (p. 147).

27. Efforts to produce saltation artificially failed (pp. 147-148).

28. The saltation was not due to mixed plantings, and can not be induced by implanting or wounding (pp. 147, 148).

29. Saltations are not due to parasites (p. 148).

30. Saltations in abundance were derived from single-conidium cultures (p. 149).

31. Saltation is very frequent as compared with bud-variation noted on potatoes and tobacco (pp. 150-151).

32. Numerous variations in test-tube cultures are reported as probable examples of saltations (p. 152).

33. The *Helminthosporium* that causes wheat foot-rot belongs to the *H. sativum* group, which consists of a large number of elementary species (p. 167).

LITERATURE CITED

- ADERHOLD, R.
 (1) 1900. Die Fusicladien unserer Obstbäume. Landw. Jahrb. 29: 541-587.
- ARCICHOVSKIJ, V.
 (2) 1908. Zur Frage über den Einfluss von $ZnSO_4$ auf eine Reihe von Generationen von *Aspergillus niger*. Centr. f. Bakt. II, 21: 430.
- ARTHUR, J. C.
 (3) 1917. Cultures of Uredineae in 1916 and 1917. Mycol. 9: 295-312.
 (4) 1920. North American Flora. 7 (pt. 4): 296.
- BAERTHLEIN, K.
 (5) 1918. Ueber bakterielle Variabilität, insbesondere sogenannten Bakterienmutationen. Centr. Bakt. I. Abt. Orig. Bd. 81: 369-475.
- BAKKE, A. L.
 (6) 1912. The late blight of barley (*Helminthosporium teres* Sacc.). Proc. Ia. Acad. Sci. 19: 93-102.
- BARBER, M. A.
 (7) 1907. On heredity in certain micro-organisms. Kan. Univ. Sci. Bul. 4: 1.
- BARY, A. DE
 (8) 1886. Ueber einige Sclerotien und Sclerotienkrankheiten. Bot. Zeit. 44: 378-387, 410-426.
 (9) 1887. Comparative morphology and biology of the fungi Mycetozoa and Bacteria. Translation by H. E. Garnsey.
- BATESON, W.
 (10) 1902. Mendel's principles of heredity. Cambridge.
- BAUR, E.
 (11) 1914. Einführung in die experimentelle Vererbungslehre. Berlin.
- BEACH, W. S.
 (12) 1919. Biologic specialization in the genus Septoria. Am. Jour. Bot. 6: 1-33.
- BEAUVERIE, J., and GUILLIERMOND, A.
 (13) 1903. Étude sur la structure du *Botrytis cinerea*. Centr. f. Bakt. II. 10: 275-311.
- BECKWITH, T. D.
 (14) 1911. Root and culm infections of wheat by soil fungi in North Dakota. Phytopathology, 1: 169-176.
- BEHRENS, J.
 (15) 1895. Phytopathologische Notizen I. Zeit. f. Pflanzenkrank. 5: 136-141.
- BENEDICT, R. C.
 (16) 1916. The origin of new varieties of Nephrolepis by orthogenetic saltation. Bul. Torr. Bot. Club, 43: 207-234.
- BISBY, G. K.
 (17) 1916. The Uredinales found upon the Onagraceae. Am. Jour. Bot. 3: 527-561.
- BLACKMAN, V. H., and WELSFORD, E. J.
 (18) 1916. Studies in the physiology of parasitism. II. Infection by *Botrytis cinerea*. Ann. Bot. 30: 389-397.

BLAKESLEE, A. F.

- (19) 1913. Mutations in *Mucor*. Year Book, Carnegie Institution, Washington, 12: 104-105.
- (20) 1920. Mutations in *Mucors*. Jour. Heredity, 11: 278-284.
- (21) 1920. Sexuality in *Mucors*. Science, n. s., 51: 375-382, 403-409.

BOLLEY, H. L.

- (22) 1912. [The work of the Department of Botany and Plant Pathology of the Experiment Station for the year 1911.] Ann. Rep. N. Dak. Agr. Exp. Sta. 22: 23-98.

BORZI, A.

- (23) 1885. *Inzengaea*, ein neuer Askomycet. Prings. Jahrb. f. wiss. Bot. 16: 450-463.

BREFELD, O.

- (24) 1890. Recent investigations of smut fungi and smut diseases. Translation by E. F. Smith. Jour. Mycol. 6: 1-8, 59-71.
- (25) 1895. Untersuchungen aus dem Gesamtgebiete der Mykologie, Heft 11: Die Brandpilze, II.

BRIERLEY, W. B.

- (26) 1918. Experimental studies in the specific value of morphological characters in the fungi. Proc. Linn. Soc. London, Oct. 1918.
- (27) ——. An albino mutant of *Botrytis cinerea*. Mentioned in the following entry.
- (28) 1920. On a form of *Botrytis cinerea* with colorless sclerotia. Phil. Trans. Roy. Soc. London Ser. B. 210: 83-114.

BRITTON, N. L., BESSEY, C. E., et al.

- (29) 1908. Aspects of the species question. Am. Nat. 42: 217-281.

BÜSGEN, M.

- (30) 1893. Ueber einige Eigenschaften der Keimlinge parasitischer Pilze. Bot. Zeit. 51: 53-72.

BURGEFF, H.

- (31) 1914, 1915. Untersuchungen ueber Variabilität, Sexualität und Erbllichkeit bei *Phycomyces nilens* Kunze. Flora, n. s. 7: 259-316; 8: 353-448.

BURGER, O. F.

- (32) 1921. Variations in *Colletotrichum gloeosporioides*. Jour. Agr. Res. 20: 723-736.

COONS, G. H.

- (33) 1916. Factors involved in the growth and the pycnidium formation of *Plenodomus fuscomaculans*. Jour. Agr. Res. 5: 713-769.

CRABILL, C. H.

- (34) 1912. Results of pure culture studies on *Phyllosticta pirina* Sacc. Science, n. s. 36: 155.
- (35) 1913. Studies on *Phyllosticta* and *Coniothyrium* occurring on apple foliage. Rep. Va. Agr. Exp. Sta. for 1911-1912: 95-115.
- (36) 1915. Dimorphism in *Coniothyrium pirinum* Sheldon. Am. Jour. Bot. 2: 449-467.

CRAMER, P. J. S.

- (37) 1907. Kritische Übersicht der bekannten Fälle von Knospenvariation. Naturk. Verhandl. v. d. Holländische Maatsch. d. Wet. Haarlem. 3 Verz., Deel VI., 3 Stuck.

- DALBEY, N. E.
 (38) 1917. Phyllachora as the cause of a disease of corn, and a general consideration of the genus Phyllachora. Trans. Ill. Acad. Sci. 10: 230-248.
- DANGEARD, P. A.
 (39) 1900. Structure et communications protoplasmiques dans le *Bactridium flavum*. Le Bot. 7: 33-45.
- DASTUR, J. F.
 (40) 1920. *Glomerella cingulata* (Stoneman) Spauld. and v. Sch. and its conidial forms, *Gloeosporium piperatum* E. and E. and *Colletotrichum nigrum* E. and Hals. on Chillies and *Carica papaya*. Ann. Appl. Biol. 6: 245-268.
 (41) 1920. The mode of infection by smut in sugar-cane. Ann. Bot. 34: 391-397.
- DIEDICKE, H.
 (42) 1902 and 1904. Ueber den Zusammenhang zwischen Pleospora- und Helminthosporium-Arten. Centr. Bakt. II, 9: 317-329, and 11: 52-59.
- DOBELL, CLIFFORD
 (43) 1913. Some recent work on mutation in micro-organisms. II. Mutations in bacteria. Jour. of Genetics, 2: 325-350.
- DUGGAR, B. M., and DAVIS, A. W.
 (44) 1919. Seed disinfection for pure culture work: the use of hypochlorites. Ann. Mo. Bot. Gard. 6: 159-170.
- DUGGAR, B. M., SEVERY, J. W., and SCHMITZ, H.
 (45) 1917. Studies in the physiology of fungi. Ann. Mo. Bot. Gard. 4: 165-173, 279-288.
- EAST, E. M.
 (46) 1908. Suggestions concerning certain bud variations. Plant World, 11: 77.
 (47) 1908. A study of the factors influencing the improvement of the potato. Ill. Agr. Exp. Sta. Bul. 127.
 (48) 1910. The transmission of variations in the potato in asexual reproduction. Ct. Agr. Exp. Sta. Rep. 33-34: 119-160.
 (49) 1917. The bearing of some general biological facts on bud variation. Am. Nat. 51: 129-143.
- EDGERTON, C. W.
 (50) 1908. The physiology and development of some anthracnoses. Bot. Gaz. 45: 367-408.
 (51) 1914. Plus and minus strains in the genus *Glomerella*. Am. Jour. Bot. 1: 244-253.
- EDGERTON, C. W., and MORELAND, C. C.
 (52) 1920. Tomato wilt. La. Agr. Exp. Sta. Bul. 174.
- ELLIOTT, J. A.
 (53) 1917. Taxonomic characters of the genera *Alternaria* and *Macrosporium*. Am. Jour. Bot. 4: 439-476.
- ERIKSSON, J.
 (54) 1887. Ueber eine Blattfleckenkrankheit der Gerste. Bot. Centr. 29: 92.
 (55) 1894. Ueber die Specialisirung des Parasitismus bei den Getreiderostpilzen. Ber. d. deut. Bot. Ges. 12: 292-331.
- FISCHER, E.
 (56) 1904. Die Uredineen der Schweiz. Beit. 3, Krypt. f. d. Schweiz, 2.

- FREEMAN, E. M., and JOHNSON, E. C.
 (57) 1911. The rusts of grains in the United States. U. S. Bur. Plant Ind. Bul. 216.
- GARDNER, M. W.
 (58) 1918. Anthracnose of cucurbits. U. S. Dept. Agr. Bul. 727.
- GARMAN, P., and STEVENS, F. L.
 (59) 1920. The genus *Septoria*, presented in tabulation with discussion. Trans. Ill. State Acad. Sci. 13: 176-219.
- GAUMANN, E.
 (60) 1917-1918. Über die Formen der *Peronospora parasitica* (Pers.) Fries. Beih. z. Bot. Centr. 35 (Abth. 1): 395-533.
- GHYS, W.
 (61) 1899. Le chrysanthème au point de vue du dimorphism. Bul. d. Soc. Hort. d. Loir-et-Cher, 30: No. 35.
- GUILLIERMOND, A.
 (62) 1920. The yeasts. Translated by F. W. Tanner. New York.
- VAN HALL, C. J. J.
 (63) 1903. Das Faulen der jungen Achlösslinge und Rhizome von *Iris florentina* und *Iris germanica*. Zeit. Pflanzenkr. 13: 129-144.
- HASSELBRING, H.
 (64) 1906. The appressoria of the anthracnoses. Bot. Gaz. 42: 135.
- HEDGCOCK, G. G.
 (65) 1906. Studies upon some chromogenic fungi which discolor wood. Rep. Mo. Bot. Gard. 17: 59-117.
- HIGGINS, B. B.
 (66) 1920. Morphology and life history of some Ascomycetes with special reference to the presence and function of spermatia. Am. Jour. Bot. 7: 435-444.
- HITCHCOCK, A. S., and CARLETON, M. A.
 (67) 1893. Preliminary report on rusts of grain. Ky. Agr. Exp. Sta. Bul. 38.
- JAKOB, G.
 (68) 1915. Zur Biologie Geranium bewohnender Uredineen. Centr. Bak., II, 44: 617-658.
- JAVILLIER, N.
 (69) 1914. Utilité du zinc pour le développement de *l'Aspergillus niger* cultivé sur milieux profonds. Bul. Soc. Chim. 4, 15-16: 568.
- JENNINGS, H. S.
 (70) 1916. Heredity, variation, and the results of selection in the uniparental reproduction of *Diffugia corona*. Genetics, 1: 407-534.
- JONES, L. R.
 (71) 1909. Pectinase, the cytolytic enzyme produced by *Bacillus carotovorus* and certain other soft-rot organisms. N. Y. Agr. Exp. Sta. (Geneva), Tech. Bul. 11.
- KIRCHNER, O.
 (72) 1891. Braunfleckigkeit der Gerstenblätter. Zeit. f. Pflanzenkr. 1: 24-26.
- KLEBAHN, H.
 (73) 1892. Kulturversuche mit heteroecischen Uredineen. Zeit. f. Pflanzenkr. 2: 258-332.

KLEBS, G.

- (74) 1900. Zur Physiologie der Fortpflanzung einiger Pilze. Jahrb. f. wiss. Bot. 35: 203.

KLICKER, A., and SCHIORMING, H.

- (75) 1900. Phénomènes d'accroissement perforant et de formation anormale des conidies chez le *Dematium pullulans* de Bary, et autres Champignons. Compt. Rend. d. Trav. d. Lab. d. Carlsberg 5: 47.

LAURENT, E.

- (76) 1899. Recherches expérimentales sur les maladies des plantes. Ann. Inst. Pasteur, 13: 1-48.

LE POUTRE, L.

- (77) 1902. Recherches sur la transformation expérimentale de bactéries banales en races parasites des plantes. Ann. Inst. Pasteur 16: 304-312.

LINDER, P.

- (78) 1887. Ueber Durchwachsungen an Pilzmycelien. Ber. d. deut. Bot. Ges. 5: 153-161.

LOTSY, J. P.

- (79) 1916. Evolution by means of hybridization. The Hague.

MAGNUS, P.

- (80) 1894. Einige Bemerkungen über die auf *Phalaris arundinacea* auftretenden Puccinien. Hedw. 33: 77.
 (81) 1894. Die systematische Unterscheidung nächst verwandter parasitischer Pilze. Hedw. 33: 362.

MAIRE, R.

- (82) 1908. Les suçoirs des *Meliola* et des *Asterina*. Ann. Myc. 6: 124.

MIYOSHI, M.

- (83) 1895. Die Durchborung von Membranen durch Pilzefäden. Jahrb. f. wiss. Bot. 28: 269-289.

MOREAU, F.

- (84) 1917. Nouvelles observations sur les mucorinées. Bul. Soc. Myc. d. France 33: 34-49.

NEGER, F. W.

- (85) 1902. Beiträge zur Biologie der Erysipheen. Flora, 90: 221-271.

NEWCOMB, F. C.

- (86) 1899. Cellulose-enzymes. Ann. Bot. 13: 49-81.

NOACK, F.

- (87) 1905. *Helminthosporium gramineum* Rabenh. und *Pleospora trichostoma* Wint. Zeit. f. Pflanzenkr. 15: 193-204.

NORDHAUSEN, M.

- (88) 1899. Beiträge zur Biologie parasitärer Pilze. Jahrb. f. wiss. Bot. 33: 1-46.

OSBORNE, T. B.

- (89) 1909. The vegetable proteids. Longmans, Green and Co., London and New York.

PAMMEL, L. H., KING, C. M., and BAKKE, A. L.

- (90) 1910. Two barley blights, with comparison of species of *Helminthosporium* upon cereals. Bul. 116, Ia. Agr. Exp. Sta.

RAVN, K.

- (91) 1900. Nogle Helminthosporium-arter og de af dem fremkaldte Sygdomme hos Byg og Havre. Bot. Tid. 23: 101-327.*

REED, G. M.

- (92) 1905. Infection experiments with *Erysiphe graminis*. Trans. Wis. Acad. Sci. 15: 135-162.
 (93) 1918. Physiological specialization of parasitic fungi. Mem. Brooklyn Bot. Gard. 1: 348-469.

REVIS, C.

- (94) 1912. The production of variation in the physiological activity of *Bacillus coli* by the use of malachite green. Proc. Roy. Soc. (London) Ser. B. 85: 192.

ROSTRUP, E.

- (95) 1894. Mykologiske meddelelser. Bot. Tid. 19: 36-51.
 (96) 1896. Biologiske Arter og Racer. Bot. Tid. 20: 116-125.

SACCARDO, P. A.

- (97) 1882——. Sylloge fungorum omnium hucusque cognitorum. Padua.

SALMON, E. S.

- (98) 1903. On specialization of parasitism in the Erysiphaceae. Beih. Bot. Centr. 14: 261.

SHELLENBERG, H. C.

- (99) 1908. Untersuchungen über das Verhalten einiger Pilze gegen Hemizellulosen. Flora, 98: 257-308.

SCHIEHMANN, E.

- (100) 1912. Mutationen bei *Aspergillus niger* van Tieghem. Zeit. Indukt. Abstamm.- u. Vererbungslehre 8: 35.

SCHROETER, J.

- (101) 1879. Entwicklungsgeschichte einiger Rostpilze. Cohn's, Beit. z. Biol. d. Pflanzen, 3: 51-93.

SHAMEL, A. D., SCOTT, L. B., and POMEROY, C. S.

- (102) 1920. Citrus-fruit improvement. A study of bud variation in the Eureka lemon. U. S. Dept. Agr. Bul. 813.
 (103) 1920. Citrus-fruit improvement. A study of bud variation in the Lisbon lemon. U. S. Dept. Agr. Bul. 815.

SHEAR, C. L., and STEVENS, N. E.

- (104) 1913. Cultural characters of the chestnut blight fungus and near relatives. U. S. Bur. Plant Ind. Circ. 131.

SHEAR, C. L., and WOOD, A. K.

- (105) 1913. Studies of fungous parasites belonging to the genus *Glomerella*. U. S. Bur. Plant Ind. Bul. 252.

SMITH, E. F.

- (106) 1899. Wilt disease of cotton, watermelon, and cowpea. U. S. Dept. Agr. Div. Veg. Phys. and Path. Bul. 17: 23.

SOROKIN, N.

- (107) ——. Ueber einige Krankheiten der Kulturpflanzen im Süd-Ussurischen Gebiet. Trudy Obshchestva Estestvoispitatelei. Imp. Univ. of Kazan.

*My notes from this important article were made from a photographic reproduction of a typewritten translation kindly loaned to the University by the Library of the U. S. Department of Agriculture.

- SPENCER, E. R.
 (108) 1921. Some of the causes of decay of Brazil-nuts. *Bot. Gaz.*, 72: 265-292.
- STAKMAN, E. C.
 (109) 1914. A study in cereal rusts. Physiological races. *Minn. Agr. Exp. Sta. Bul.* 138.
- STAKMAN, E. C., and LEVINE, M. N.
 (110) 1919. Effect of certain ecological factors on the morphology of the urediniospores of *Puccinia graminis*. *Jour. Agr. Res.* 16: 43-77.
- STAKMAN, E. C., and PIEMEISEL, F. J.
 (111) 1917. Biologic forms of *Puccinia graminis* on cereals and grasses. *Jour. Agr. Res.* 10: 429-495.
- STAKMAN, E. C., PIEMEISEL, F. J., and LEVINE, M. N.
 (112) 1918. Plasticity of biologic forms of *Puccinia graminis*. *Jour. Agr. Res.* 15: 221-249.
- STAKMAN, L. M.
 (113) 1920. A Helminthosporium disease of wheat and rye. *Minn. Agr. Exp. Sta. Bul.* 191.
- STEINBERG, R. A.
 (114) 1917. A study of some factors influencing the stimulative action of zinc sulphate on the growth of *Aspergillus niger*. I. The effect of the presence of zinc in the culture flasks. *Mem. Torr. Bot. Club*, 17: 287-293.
- STEVENS, F. L.
 (115) 1919. Two Illinois rhubarb diseases. *Ill. Agr. Exp. Sta. Bul.* 213.
 (116) 1919. Foot-rot disease of wheat—historical and bibliographic, *Bul. Ill. Nat. Hist. Surv.* 13: Art. 9.
 (117) 1920. Foot-rot of wheat. *Science*, n. s., 51: 517-518.
- STEVENS, F. L., and HALL, J. G.
 (118) 1909. Variation of fungi due to environment. *Bot. Gaz.* 48: 47-71.
- STEWART, F. C., and HODGKISS, H. E.
 (119) 1908. The *Sporotrichum* bud-rot of carnation and the silver top of June grass. N. Y. (Geneva) *Agr. Exp. Sta. Tech. Bul.* 7.
- STOUT, A. B.
 (120) 1915. The establishment of varieties in *Coleus* by the selection of somatic variations. *Carnegie Inst. of Wash. Pub.* 218.
- VAUGHAN, V. C.
 (121) 1915. Mutation in bacteria. *Jour. Lab. and Clin. Med.* 1: 145.
- VRIES, H. DE
 (122) 1901. *Die Mutations Theorie*.
- WARD, H. M.
 (123) 1888. A lily disease. *Ann. Bot.* 2: 319-382.
- WARTENWEILER, A.
 (124) 1918. Beiträge zur Systematik und Biologie einiger Plasmopara-arten. *Ann. Myc.* 16: 249-299.
- WATERMAN, H. J.
 (125) 1912. Mutatie bij *Penicillium glaucum* en *Aspergillus niger* onder invloed van bekende factoren. *Kon. Akad. Wetensch. Amsterdam, Verslagen Natuurkundige*, 21: 33-38.

WIEDEMANN, C.

- (126) 1907. Morphologische und physiologische Beschreibung einiger *Penicillium* Arten. Centr. f. Bakt. II. 19: 675-690.

WOLF, F.

- (127) 1909. Ueber Modificationen und experimentelle ausgelöste Mutationen von *Bacillus prodigiosus* und anderen Schizophyten. Zeit. induct. Abstamm.- u. Vererbungslehre 2: 90-132.

WOLFF, R.

- (128) 1874. Der Brand des Getreides. Halle.

ZOFF, W.

- (129) 1881. Zur Entwicklungsgeschichte der Ascomyceten. Chaetomium. Nova Acta der k. Leop.-carol-deutschen Akad. Naturf. Vol. 42.

APPENDIX

METHODS

For measuring conidia.—The following procedure was found convenient. An ordinary bacteriological iridium wire was plunged into vaseline and then so laid across a microscope slide as to leave on it two complete, narrow, thin streaks of vaseline about 6 mm. apart. A small drop of water was then placed between these two vaseline lines and the conidia-sample added and evenly distributed. When the cover-glass was placed the vaseline prevented the conidia from scattering, and rendered it possible by means of the mechanical stage to measure every conidium, thus securing a more representative sample than would be the case if some conidia, perhaps of some particular class, were allowed to float away.

In sampling from standard cultures for purpose of conidia-measurement, a portion of a shoot about 6 mm. long that was evenly and densely covered with conidia was removed to the slide. Shoots were all evenly and abundantly sporiferous except in cases where entire shoots or parts of shoots were paler and bore more aerial mycelium.

To avoid unconscious selection in measuring conidia a mechanical stage was used, and all conidia encountered in certain predetermined positions in the field of vision were measured. Length was measured from extreme tip to extreme base; breadth, at the thickest point. Measurements falling exactly between two classes were temporarily so recorded, and later distributed equally between the two adjacent classes.

Measurements for coefficients are easily made by projecting the outline of the conidium, by means of a camera, upon quarter-section paper of convenient ruling. The paper may readily be oriented with the conidium in any desired relation.

The rag doll for inoculations.—An adaptation of the rag-doll seed-tests was found useful in inoculations. The doll was made of a strip of cloth, 6×50 cm. which was rolled to a cylinder about 6×2.5 cm. and placed in a test-tube 2.5×25 cm. with water, and autoclaved. In use the roll was removed to a sterile Petri-dish 17 cm. in diameter, the water removed to the desired degree by wringing, and the doll unrolled by the use of sterile forceps (Pl. XXXIII). Seedlings raised aseptically were

then laid on the unrolled doll and inoculation made in the desired manner. The doll was then rolled up, inclosing the seedlings, and placed again in the test-tube. For purposes of root inoculation the doll was suspended in the test-tube about five centimeters from its bottom.

Inoculations in soil.—In addition to the usual pot and bench inoculations, it was found convenient to use wide-mouth vials, 12×70 mm. (see page 128), which were lined with stiff paper (so cut as to open easily, Pl. XXXIII), filled with soil, and autoclaved. The paper envelope with the enclosed soil could readily be withdrawn from the vial, and opened in order to insert the seed, seedling, or inoculum, and later repeated examinations could be made without greatly disturbing the plant.

Imbedding conidia.—Conidia were raised under standard conditions (see next paragraph) and the entire shoot bearing them, together with the adjacent agar—a strip about 4 mm. wide—was removed to chrome-acetic killing-fluid, and imbedded in the usual way.

Procedure to secure standard conditions.—Petri dishes of 12 c.c. washed agar, when solid, were inoculated in the center with the desired organism. When, in the course of a few days, this had attained a colony-diameter of 2 to 3 cm., wheat shoots, autoclaved in water, were laid on the surface of the agar, the basal ends of the shoots touching the edge of the advancing colony. Usually about six shoots were used per plate, resulting in ample material. Aseptic wheat shoots were secured by the method described in the next paragraph. The shoots were cut for autoclaving when they were about 2-3 cm. in length. This medium was selected as being of appropriate composition and only very slightly variable. The washed agar in uniform quantity in Petri dishes of the same depth gave a uniform humidity, while the mode of inoculation was also uniform, doing away with many errors that arise when the quantity of the inoculum is a variable factor.

Growing aseptic seedlings.—Seeds were treated three hours in 20% fresh Javelle water, rinsed with sterile distilled water, and germinated on damp filter-paper in moist chambers (44). In the latter part of the study para-toluene-sodium-sulphochloramide was substituted for Javelle water in seed-disinfection. It was used in 0.5% aqueous solution, the seeds being immersed for twenty minutes. Such preliminary tests as we have made, indicate that a solution of 0.25 to 0.5% is efficient as a fungicide, while such solutions may be safely used without injury to the grain. It certainly possesses value for such uses in the laboratory, and may be of service as a fungicide in other connections. A rather

extensive test of its utility against the cereal smuts is now in progress. Para - toluene - sodium - sulphochloramide is a chemical of the formula $(p)CH_3C_6H_4SO(NCl)ONa$. My supply was secured from the Abbott Laboratories in Chicago, where it is manufactured.

Preparation of potato plugs.—Instead of the ordinary potato plug it was found useful to place a glass slip in a test-tube as in Fig. 2, p. 94, then to crowd into the tube a potato slice, bringing it into contact with the glass slip, and, at its angles, with the walls of the test-tube. This gave, in addition to the usual surface for observation, the places where the potato made contact with the glass slip and with the walls of the test-tube.

A device for the study of humidity.—To study the effect of changes of humidity on conidiophores and conidia, test-tubes were fitted with glass slips, and sterile wheat shoots laid across them (Fig. 2, p.94). The region 1 is of about 90% relative humidity; that of region 2 is below 90%. Combustion boats full of agar were used (Fig. 2) to secure high humidity for the whole culture.

LIST OF HELMINTHOSPORIUMS USED FOR PURPOSES OF COMPARISON

H. No. 1. Isolated by F. L. Stevens May 18, 1918, from wheat diseased with foot-rot, from Madison Co., Ill.

H. No. 2. *H. ravenelii*, isolated by F. L. Stevens Jan. 17, 1920, from specimen received from A. B. Seymour, collected at Lake Charles, La., Oct., 1919, by E. E. Barnes. This specimen was thoroughly typical, and no doubt as to the determination can be entertained.

H. No. 3., labeled *H. teres*. Received from A. L. Bakke Jan. 5, 1920. Culture isolated Jan. 9, 1911.

H. No. 4. Isolated by F. L. Stevens Jan. 16, 1920, from specimens from Iowa labeled *H. teres*.

H. No. 5. Isolated by F. L. Stevens Jan. 16, 1920, from barley, from specimen from Iowa labeled *H. gramineum*.

H. No. 6. From E. C. Stakman, Jan. 20, 1920. Isolated from blighted seedling of Marquis wheat.

H. No. 7. From E. C. Stakman, Jan. 20, 1920. Isolated from Marquis wheat.

H. No. 8. From E. C. S. (E. C. Stakman), Jan. 20, 1920. Isolated from Marquis wheat growing in sterile soil.

H. No. 9. From E. C. S., Jan. 20, 1920. Isolated from roots of Marquis wheat seedlings.

H. No. 10. From E. C. S., Jan. 20, 1920. Isolated from barley, Madison, Wis., "2-1919."

H. No. 11. From E. C. S., Jan. 20, 1920. Isolated in 1914 from wheat in Minnesota.

H. No. 12, labeled *H. gramineum*, from E. C. S., Jan. 20, 1920. Isolated from barley, Carver, Minn., 1914.

H. No. 13, labeled *H. sativum*. From L. W. Durrell, Feb. 6, 1920. From barley grown on the agronomy farm, Ames, Iowa. Isolated by Durrell about 1918 "from spots or lesions pointed out as typical by Dr. A. G. Johnson."

No. 14, labeled *H. sativum*. From L. W. Durrell, Feb. 6, 1920. From barley. Same origin as No. 13.

H. No. 15, labeled *H. teres*. From L. W. Durrell, Feb. 6, 1920, dated May 22, 1918. Same data as No. 13.

H. No. 16, labeled *H. teres*. Same data as for No. 13.

H. No. 17, labeled *H. gramineum*. Same data as for No. 13.

H. No. 18, labeled *H. avenae*. Same data as for No. 13, except that isolation was from oats, grown in rust nursery.

H. No. 19, labeled *H. gramineum*. From H. Coons, Feb. 16, 1920. Isolated from barley in 1918.

H. No. 20, labeled *H. teres*. From Centraal Bureau voor Schimmelcultures. Culture of Feb. 11, 1920. Isolated from late blight of barley by Bakke and sent in 1914 to Dr. Westerdijk, who wrote me that "the fungus had since been cultured on oatmeal (roll culture) and ears of barley."

H. No. 21, labeled *H. interseminatum*. From Centraal Bureau voor Schimmelcultures, March 12, 1920. Culture of Feb. 11, 1920. Received by Dr. Westerdijk from Miss Dale in 1912 and cultured on oatmeal or on corn-meal.

H. No. 22. From Wanda Weniger, Mar. 24, 1920. Isolated April 28, 1919, from kernels of Arnautka wheat in North Dakota. Used in field studies in 1919.

H. No. 23, labeled *H. teres*. From Wanda Weniger, Mar. 24, 1920. Isolated Feb. 27, 1920, from blade of barley collected at Mandan, N. Dak. July 1919.

H. No. 24. From Wanda Weniger, Mar. 24, 1920. Isolated Feb. 28, 1920, from first node of Red Durum wheat collected at Fargo, N. Dak., Aug. 1919.

H. No. 25. From Wanda Weniger, Mar. 24, 1920. Isolated Nov. 20, 1918, from blade of rye collected at Fargo, N. Dak. Used in field studies in 1919.

H. No. 26, labeled *H. sativum*. From Wanda Weniger, Mar. 24, 1920. Isolated July 12, 1919, from blade of wheat collected at Fargo.

H. No. 27. From Wanda Weniger, Mar. 24, 1920. Isolated from blade of "De" wheat collected at Fargo. Isolated Aug. 18, 1919, and used in field studies in 1919.

Cultures 22-27 were grown on 2 or 3% potato-agar with 2% dextrose from the time of their isolation until received by me. The species determinations were stated to be based on the host; not on morphological characters.

H. No. 29. From G. N. Hoffer. "Culture B. 201a." Isolated from a broken corn-stalk from Ft. Branch, Ind., Aug. 13, 1919.

H. No. 30. From G. N. H. (G. N. Hoffer). "Culture B. 180." Isolated from brown, water-soaked lesions on the sheath of a corn-leaf. Plant was collected at Sullivan, Ind., Aug. 12, 1919.

H. No. 31. From G. N. H. "Culture B. 170 A." Isolated from small brown spots on corn leaves. Collected at Delphi, Ind., Aug. 8, 1919.

H. No. 32. From G. N. H. "Culture B. 165." Was isolated from small yellow spots on corn leaves collected at Battle Ground, Ind., Aug. 7, 1919.

H. No. 34. From G. N. H. "Culture B. 124." Isolated from dark brown, irregularly shaped lesions on corn stalks collected at Ames, Iowa, July 25, 1919.

H. No. 36. From C. E. Kurtzweil. Labeled "3% oat 206 5-40." Isolated from a dead corn-stalk in Tennessee.

H. Nos. 37 and 38. Isolated by F. L. S. (F. L. Stevens) Aug. 8, 1920, from wheat grains after treatment with Javelle water.

H. No. 39. Isolated by F. L. S. Nov. 20, 1920, from *Chaetochloa* (millet). Conidium short, 3-septate.

H. No. 40. Isolated by F. L. S. Nov. 20, 1920, from same plant as No. 39. Conidium long, narrow.

H. No. 41. Isolated by F. L. S. Dec. 3, 1920, from sorghum.

H. No. 42. Isolated by F. L. S. Dec. 10, 1920, from millet.

H. No. 43. Isolated by F. L. S. Dec. 10, 1920, from sorghum.

H. No. 44. Isolated by W. L. Blain Dec. 20, 1920, from wheat.

H. No. 45. Isolated by F. L. S. from association with H. No. 44.

H. No. 46. From E. J. Butler, Mar. 10, 1921. Isolated from wheat by R. E. Massey in Khartoum in the Anglo-Egyptian Sudan. The statement is made that "the straw was completely rotted through the base, and broke off short when handled. The fungus was present in pure culture on the crown and roots."*

DISCUSSION OF FOREGOING LIST WITH SEVERAL BRIEF DESCRIPTIONS

H. Nos. 29-32, though perhaps not quite identical, agreed closely with each other. They were mostly 5-celled, with the central cell inequilateral and the two end-cells pale. In conidial measurements they approached rather closely to *H. inaequalis* Shear, *H. tritici* P. Henn., and *H. geniculatum* T. & E.

H. Nos. 13 and 14 were of identical parentage.

H. Nos. 15 and 16 were from one strain though separated by several transfers. The original strain (15) was sent because the growth (16) did not look characteristic.

H. No. 11 usually gave no conidia at all and was quite distinct in culture characters and in color and septation of conidia.

H. Nos. 36, 40, and 41 are closely alike in morphological characters. H. Nos. 40 and 41 differ from H. No. 36 in that they do not possess the abundant aerial mycelium. Nos. 40 and 41 differ in zonation and in amount of aerial mycelium, and all three of these forms differ somewhat in their conidial graphs. They also differ in mycelial characters and in the way in which they penetrate wheat cells, though all three do the latter vigorously, completely occupying the cells and causing rotting. The three had best be regarded as elementary species of the same Linneon.

Description of H. No. 36.—Conidia mostly long and slender (Pl. XXI,*a*) but very variable in length. Stipe short but distinct. Apex pale. No constrictions at the septa. Septa usually thick and obvious. Conidia tapering very slightly from point of maximum thickness toward each end; straight or slightly arched. Episorium brittle; endosporium gelatinous. Conidiophores uniform; sterile portion thin, slender, quite long (350 μ), about 4 μ thick, smooth, brown, cells 24-28 μ long, not constricted at the septa; fertile portion slightly thicker and darker, cells short, therefore geniculations crowded, growth on agar characterized by abundant aerial mycelium (Pl. X)—more abundant than in any other form studied—as was also evident under standard conditions.

*From letter from E. J. Butler dated Feb. 28, 1921.

Isolated from dead corn-stalk in Tennessee by C. E. Kurtzweil.

Data on conidial length of H. No. 36 are as follows:

Frequency,	1	2	3	3	6	11	12	10	12	17	21	9
Microns,	34	37.1	40.8	44.2	47.6	51	54.4	57.8	61.2	64.6	68	71.4
Frequency, 10	15	12	11	7	6	3	3	0	2	1		
Microns,	74.6	78.2	81.8	85	88.4	91.8	95.2	98.6	102	105.4	108.8	

Conidial breadth ranged uniformly from 10.2 to 13.6 microns.

Data on septation are as follows:

Frequency,	3	3	6	13	17	8	6	1	1
Septa,	4	5	6	7	8	9	10	11	12

Description of H. No. 39.—Conidia short, quite uniform in size, cylindrical or very slightly tapering from point of maximum thickness (Pl. XXI, *b*). Hilum usually evident. Septa thick, usually three; no constriction. Apical spot barely perceptible. Episporium brittle. Endosporium gelatinous. Conidiophores uniform; sterile portion 190-250 μ long, smooth, 3.5 μ . thick, not constricted, cells about 17-24 μ long; fertile portion much darker and nearly twice as thick as the sterile part, genicula very congested, numerous, usually 35-70 μ long. Conidia remaining attached in very large clusters.

Data on conidial length are as follows:

Frequency,	1	1	1	2	13	19	19	9	3	2	0	1
Microns,	6.8	10.2	13.6	17	20.4	23.8	27.2	30.6	34	37.4	40.8	44.2

Conidial breadth was quite uniformly 10.2 μ .

Data on septation are as follows:

Frequency.....	3	1	31
Septa.....	1	2	3

This organism produced on wheat many infection points with the appressoria and "callus," but differed from H. No. 1 in the minute characters of the infection spot.

H. No. 46 is very closely like H. No. 39. Data on the conidial length of H. No. 46 are as follows:

Frequency.....	1	3	4	8	15	4	1
Microns.....	8	20.4	23.8	27.2	30.6	34	37.4

Conidial breadth was uniformly as follows:

Frequency.....	2	11	1
Microns.....	6.8	10.2	13.6

The data on septation are:

Frequency.....	1	15
Microns.....	2	3

GENERAL EXPLANATION OF GRAPHS

All graphs on a page are drawn to the same scale. In all graphs of length and breadth the class value is 3.4μ . All computations are based on class values. These in case of length and breadth can be converted to microns by use of the factor 3.4, or by the following table of equivalents:

Class	Microns	Class	Microns	Class	Microns
1 =	3.4	13 =	44.2	25 =	85.
2 =	6.8	14 =	47.6	26 =	88.4
3 =	10.2	15 =	51.	27 =	91.8
4 =	13.6	16 =	54.4	28 =	95.2
5 =	17.	17 =	57.8	29 =	98.6
6 =	20.4	18 =	61.2	30 =	102.
7 =	23.8	19 =	64.6	31 =	105.4
8 =	27.2	20 =	68.	32 =	108.8
9 =	30.6	21 =	71.4	33 =	112.2
10 =	34.	22 =	74.8	34 =	115.6
11 =	37.4	23 =	78.2		
12 =	40.8	24 =	81.6		

The customary symbols are used in presenting the data of the graphs, f, designating frequency; M, mean; σ , standard deviation; and CV, co-efficient of variability.

FIGURE A

Conidial length of *H. No. 1* grown on corn-meal agar made at different temperatures: Graph 1, on agar made at 100°; Graph 2, on agar made at 85°; Graph 3, on agar made at 60°; Graph 4, on agar made at 43°.

Graph	f	M	σ	CV
1	132	21.96 $\pm$.16	2.84 $\pm$.11	12.03 $\pm$.54
2	113	21.96 $\pm$.13	2.18 $\pm$.09	9.93 $\pm$.44
3	129	21.15 $\pm$.17	2.89 $\pm$.12	13.68 $\pm$.58
4	149	22.02 $\pm$.17	3.10 $\pm$.12	14.09 $\pm$.56

FIGURE A

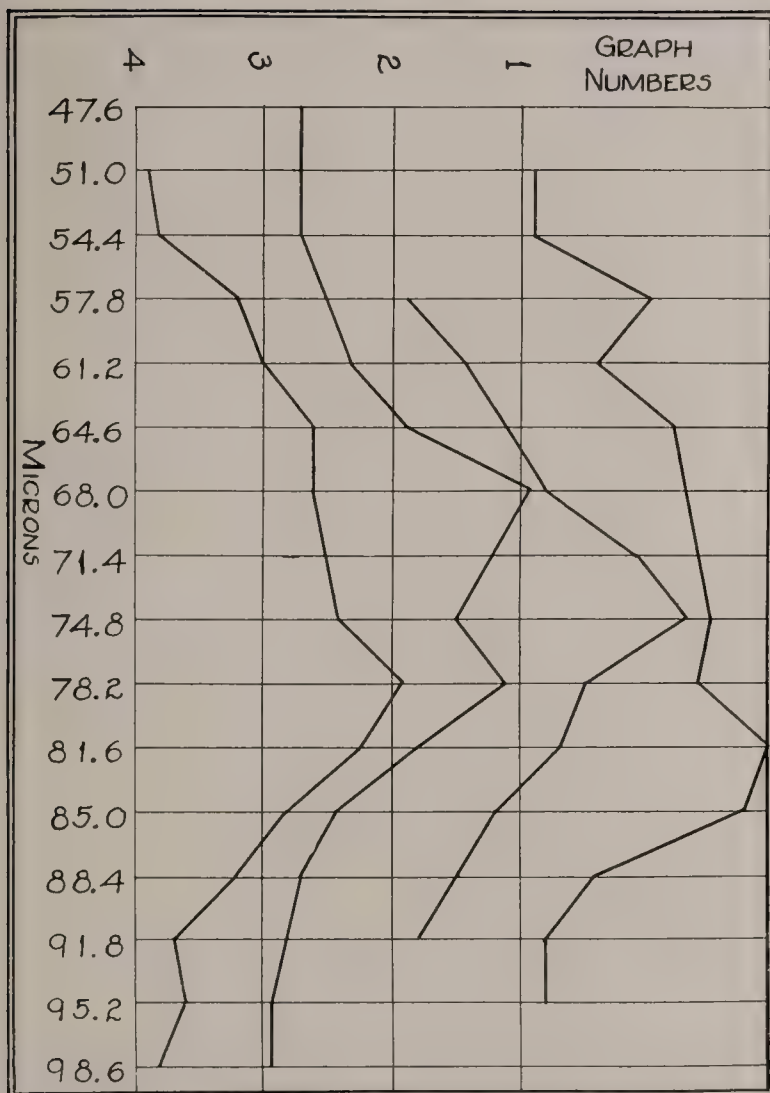


FIGURE B

Conidial breadth of H. No. 1 grown on corn-meal agar made at different temperatures: Graph 5, on agar made at 60°; Graph 6, on agar made at 43°.

Graph	M	σ	CV
5	5.50 $\pm$.04	.22 $\pm$.03	4.06 $\pm$.61
6	5.50 $\pm$.03	.18 $\pm$.02	3.31 $\pm$.40

Graph 6A, conidial breadth of H. No.1 grown under standard conditions. (See app., p. 180).

Graph	f	M	σ	CV
6A	57	6.03 $\pm$.04	0.55 $\pm$.34	9.13 $\pm$.57

Conidial septa of H. No. 1 grown on corn-meal agar: Graph 7, septa on agar made at 60°; Graph 8, septa on agar made at 43°.

Graph	M	σ	CV
7	7.30 $\pm$.21	1.58 $\pm$.14	21.72 $\pm$ 2.12
8	7.05 $\pm$.12	1.11 $\pm$.09	15.86 $\pm$ 1.31

FIGURE B

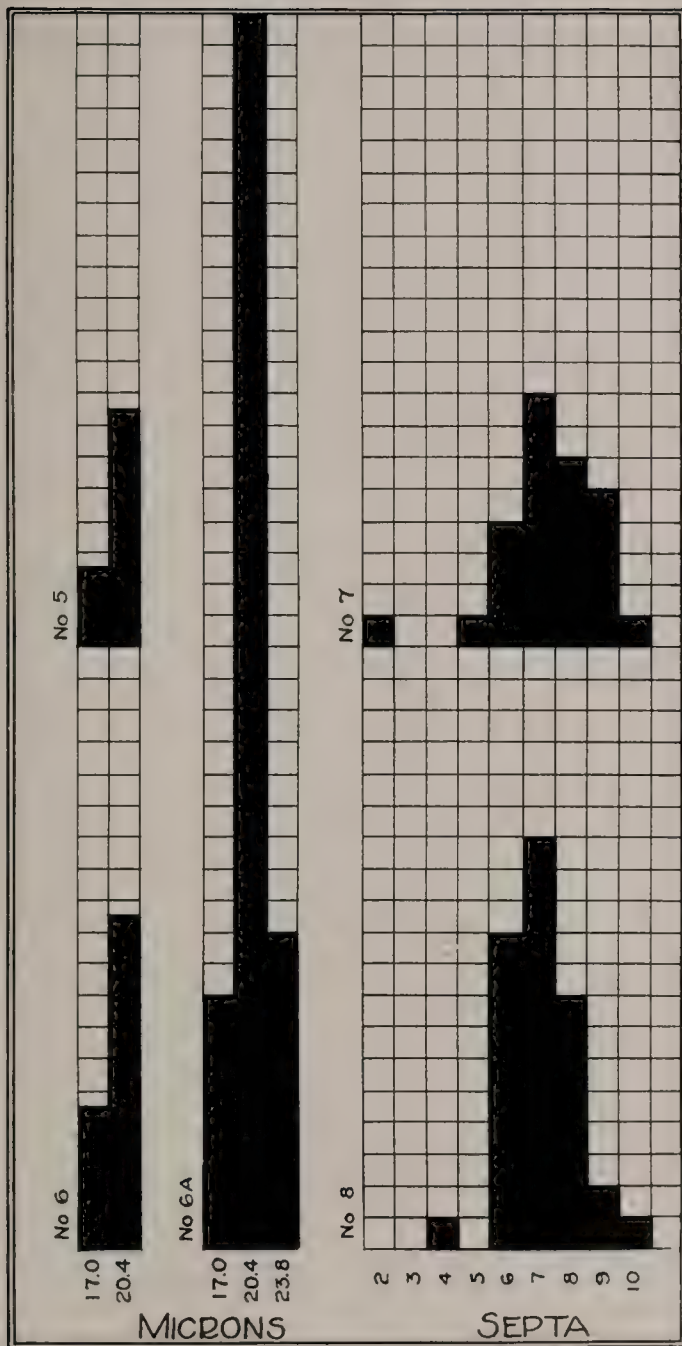


FIGURE C
 Conidial length of H. No. 1 when grown on plain agar and on agar with various amounts of corn-meal agar: Graph 9, length on plain agar; Graph 10, on plain agar $\frac{3}{4}$, plus $\frac{1}{4}$ corn-meal agar; Graph 11, on plain agar $\frac{1}{2}$, plus $\frac{1}{2}$ corn-meal agar; Graph 12, on plain agar $\frac{1}{4}$ plus $\frac{3}{4}$ corn-meal agar.

Graph	f	M	σ	CV
9	66	19.51 $\pm$.18	2.27 $\pm$.13	11.67 $\pm$.61
10	63	20.36 $\pm$.21	2.47 $\pm$.14	12.13 $\pm$.73
11	59	21.03 $\pm$.18	2.10 $\pm$.13	10.01 $\pm$.62
12	65	21.76 $\pm$.29	3.51 $\pm$.20	16.15 $\pm$.98

FIGURE C

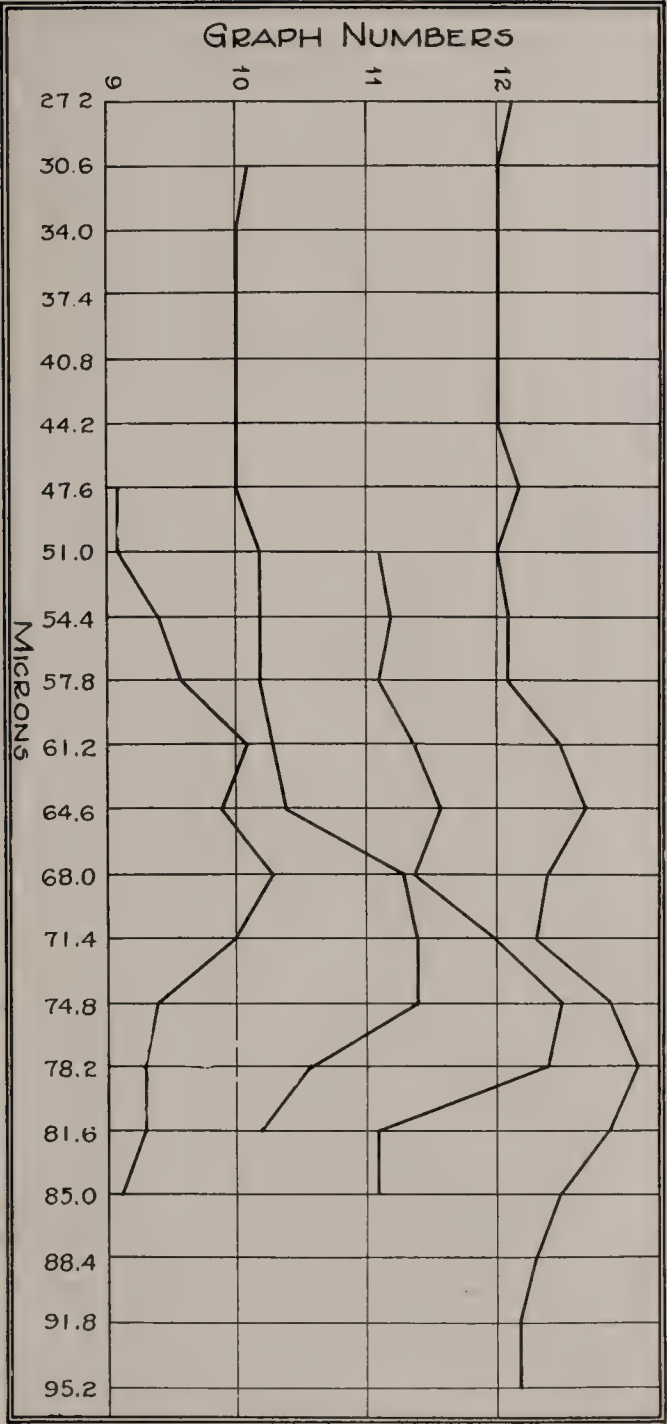


FIGURE D

Conidial breadth of H. No. 1 grown on green-wheat agar of different compositions: Graph 13, on washed agar $\frac{1}{4}$, green-wheat agar $\frac{3}{4}$; Graph 14, on washed agar $\frac{3}{4}$, green-wheat agar $\frac{1}{4}$.

Graph	f	M	σ	CV
13	14	$6.10 \pm .06$	$0.38 \pm .04$	$6.32 \pm .80$
14	44	$5.98 \pm .07$	$0.71 \pm .05$	$11.87 \pm .86$

Conidial septa of H. No. 1: Graph 15, grown on washed agar $\frac{1}{4}$, green-wheat agar $\frac{3}{4}$; Graph 16, grown on washed agar $\frac{3}{4}$, green-wheat agar $\frac{1}{4}$.

Graph	f	M	σ	CV
15	65	$3.83 \pm .18$	$2.22 \pm .13$	58.02 ± 4.10
16	46	$5.63 \pm .15$	$1.56 \pm .11$	27.80 ± 2.10

FIGURE D

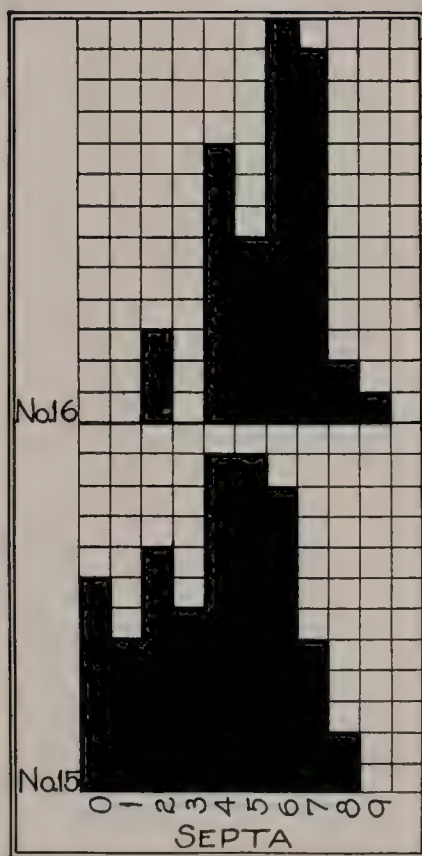


FIGURE E

Conidial length of *H. No. 1* grown on corn-meal agars of different quantities in standard 100 mm.-Petri-dishes: Graph 17, on 66 c.c. of agar; Graph 18, on 12 c.c. of agar.

Graph	M	σ	CV
17	$17.20 \pm .22$	$4.03 \pm .15$	$23.45 \pm .95$
18	$19.85 \pm .25$	$3.07 \pm .17$	$15.51 \pm .91$

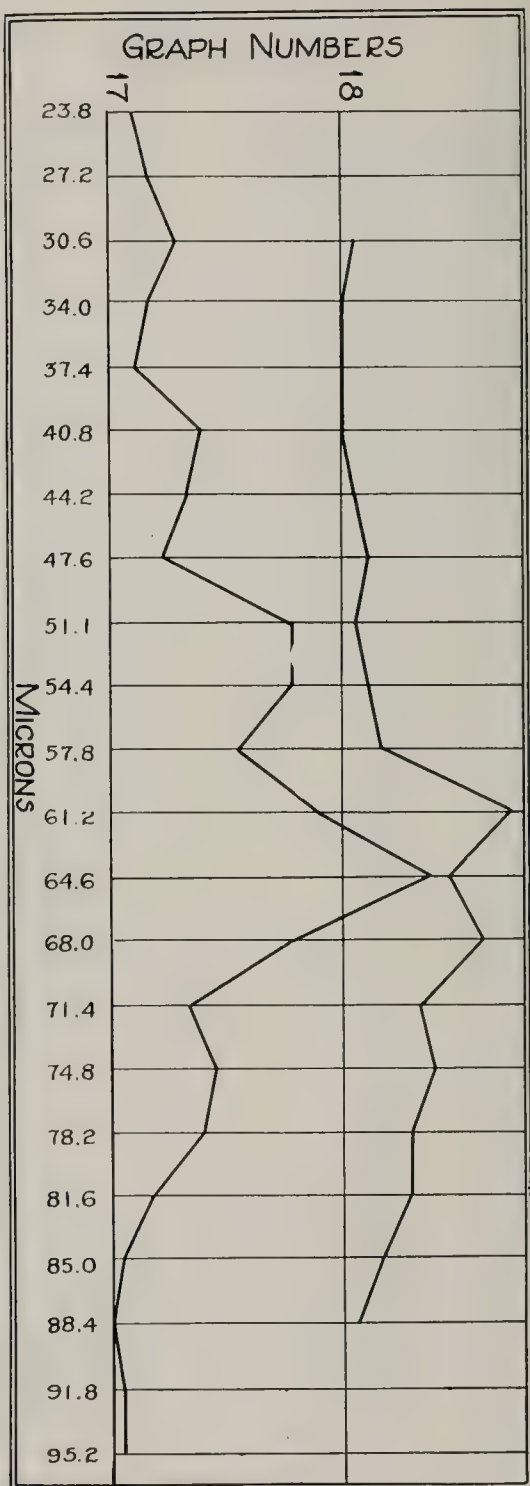
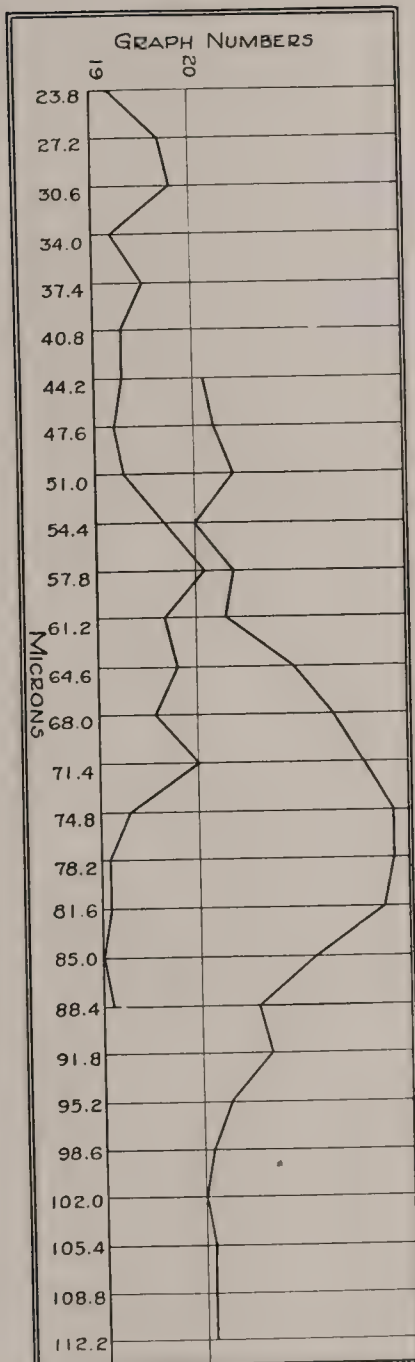


FIGURE F



Conidial length of *H. No. 1* on old wheat straw at different humidities; Graph 19, grown in comparatively dry conditions near the top of the test-tube; Graph 20, grown in humid conditions near the bottom of the tube.

Graph	f	M	σ	CV
19	—	15.67 $\pm$.33	4.77 $\pm$.24	30.46 $\pm$ 1.66
20	147	22.39 $\pm$.18	3.04 $\pm$.13	15.22 $\pm$.61

FIGURE G

Conidial length of H. No. 1 grown on live wheat shoots at three temperatures: Graph 21, fungus grown at 15°; Graph 22, fungus grown at 20°; Graph 23, fungus grown at 30°.

Graph	f	M	σ	CV
21	265	24.30 $\pm$.12	3.01 $\pm$.08	12.38 $\pm$.36
22	225	22.71 $\pm$.13	2.97 $\pm$.09	13.08 $\pm$.42
23	41	19.92 $\pm$.29	2.76 $\pm$.20	13.86 $\pm$ 1.05

FIGURE G

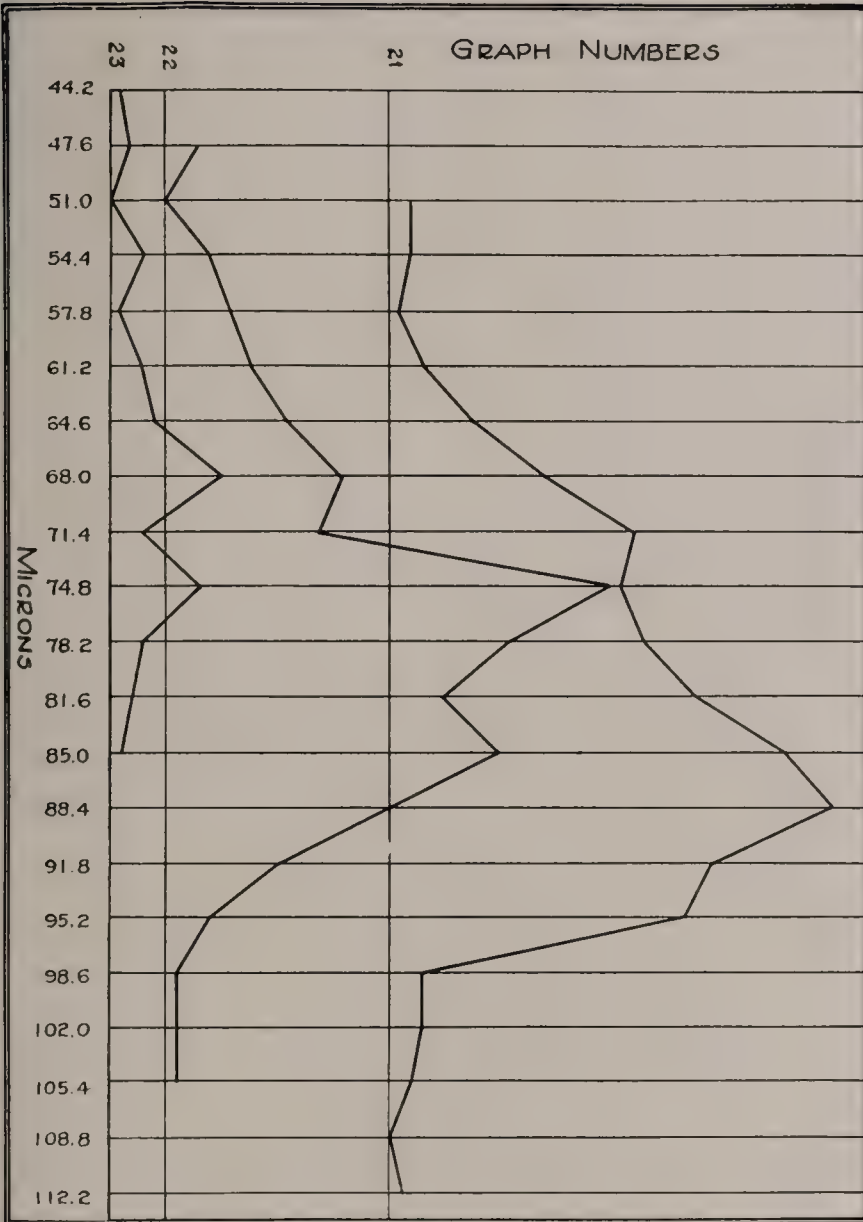


FIGURE H

Conidial length of H. No. 1 grown on plain agar with various nutrients added: Graph 24, with saccharose added; Graph 25, with "buckwheat flour" added; Graph 26, with corn meal added; Graph 27, with wheat flour added; Graph 28, with corn-starch added; Graph 29, tapioca added; Graph 30, rice added; Graph 31, Brazil-nut fragments added; Graph 32, wheat fragments added. Graph 33, conidial length in the region of inhibition near the edge of the colony on plain agar.

Graph	f	M	σ	CV
24	54	10.37 $\pm$.26	2.83 $\pm$.18	27.35 $\pm$ 1.19
25	67	21.41 $\pm$.21	2.64 $\pm$.15	12.37 $\pm$.15
26	99	21.80 $\pm$.24	3.66 $\pm$.17	16.81 $\pm$.82
27	42	23.21 $\pm$.21	2.11 $\pm$.15	9.09 $\pm$.66
28	53	33.37 $\pm$.20	2.24 $\pm$.14	9.59 $\pm$.62
29	101	15.70 $\pm$.27	4.09 $\pm$.19	26.08 $\pm$ 1.31
30	106	19.72 $\pm$.23	3.65 $\pm$.16	18.48 $\pm$.88
31	53	22.64 $\pm$.34	3.75 $\pm$.24	16.59 $\pm$ 1.11
32	88	23.03 $\pm$.19	2.73 $\pm$.13	11.87 $\pm$.61
33	43	21.41 $\pm$.19	1.88 $\pm$.13	8.79 $\pm$.63

FIGURE H

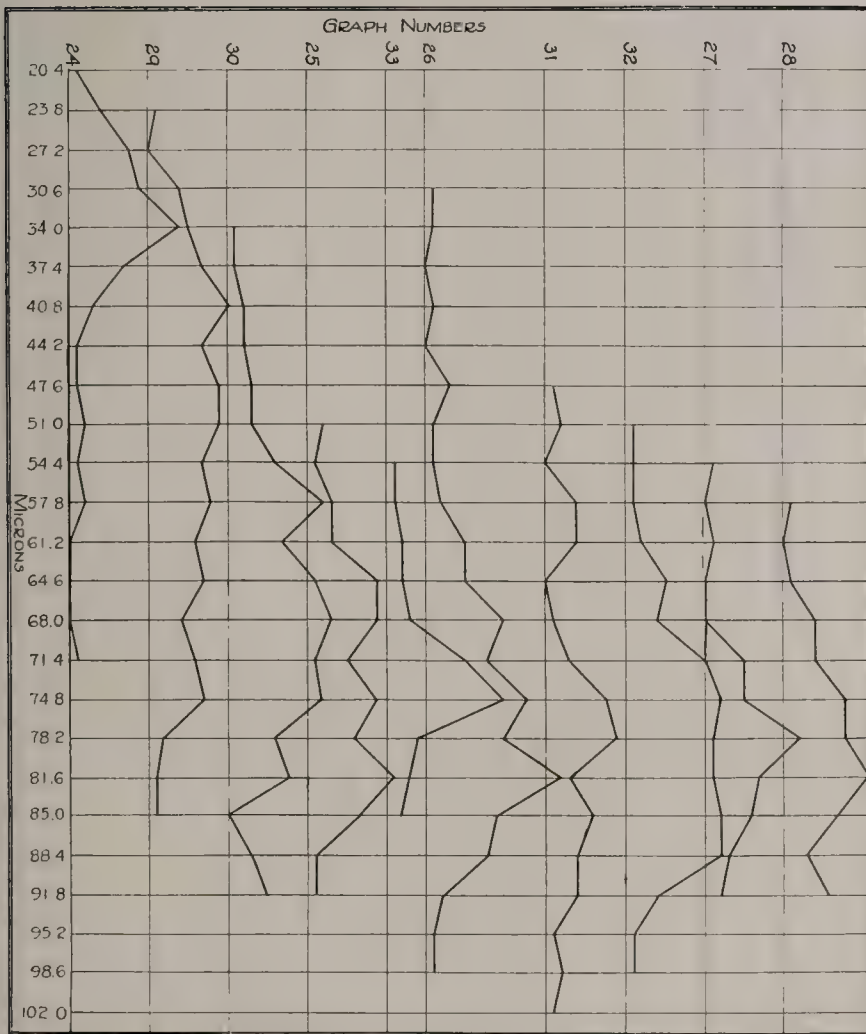
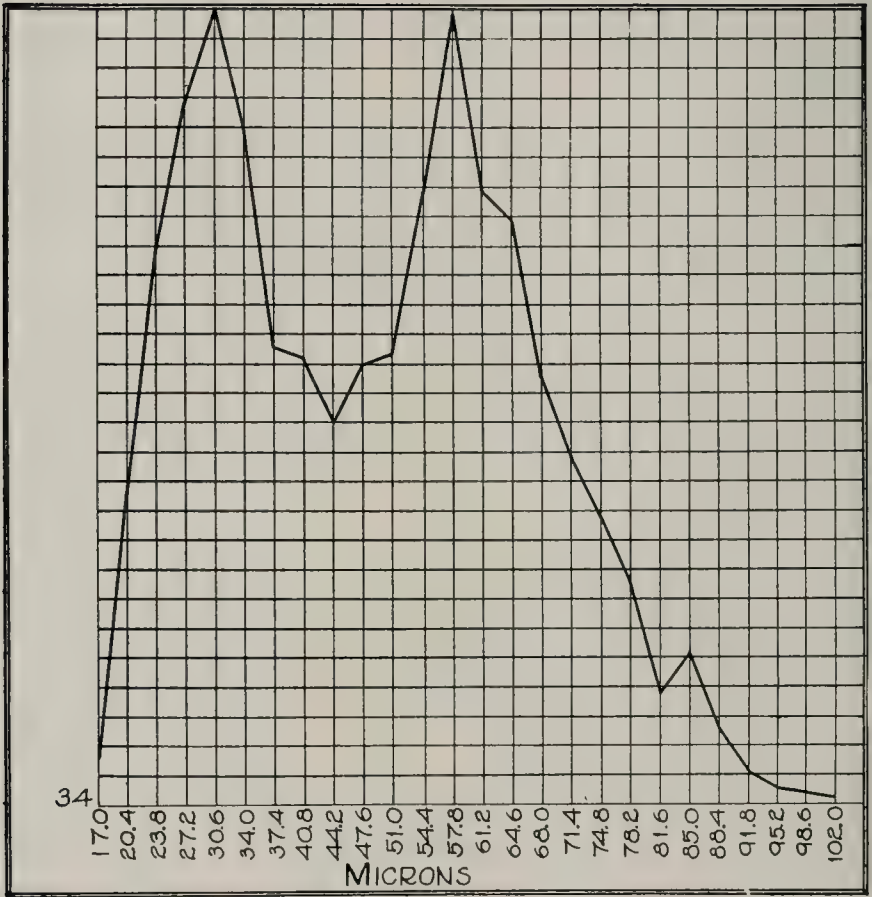


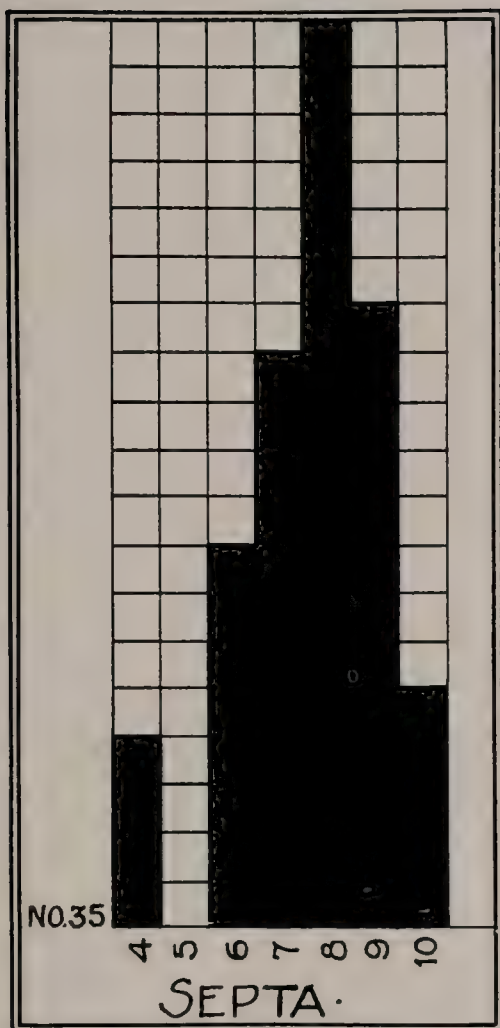
FIGURE I



Length of 1646 conidia of H. No. 1 grown on corn-meal agar.
See also pp. 120-121.

Graph	M	σ	CV
34	$14.34 \pm .08$	$5.35 \pm .06$	$37.35 \pm .70$

FIGURE J



Conidial septation of H. No. 1.

Graph
35

f
58

M
 $7.91 \pm .08$

σ
 $.99 \pm .—$

CV
 $12.51 \pm .79$

FIGURE K

Graphs of conidial length of H. No. 1 grown under standard conditions (see app. p. 180): Graphs 36-40 represent respectively plates a-e; Graph 41 represents plate e'; and Graph 42 is a composite of plates a, b, c, d, e' (see p. 120).

Graph	f	M	σ	CV
36	123	$23.21 \pm .15$	$2.36 \pm .10$	$10.02 \pm .46$
37	107	$22.51 \pm .15$	$2.54 \pm .10$	$11.28 \pm .49$
38	142	$22.59 \pm .16$	$2.87 \pm .11$	$12.70 \pm .51$
39	180	$22.42 \pm .17$	$3.42 \pm .12$	$15.25 \pm .55$
40	—	$21.18 \pm .18$	$3.55 \pm .13$	$16.80 \pm .63$
41	647	$22.71 \pm .05$	$2.26 \pm .04$	$9.95 \pm .01$
42	1199	$22.62 \pm .05$	$2.76 \pm .03$	$12.22 \pm .16$

FIGURE K

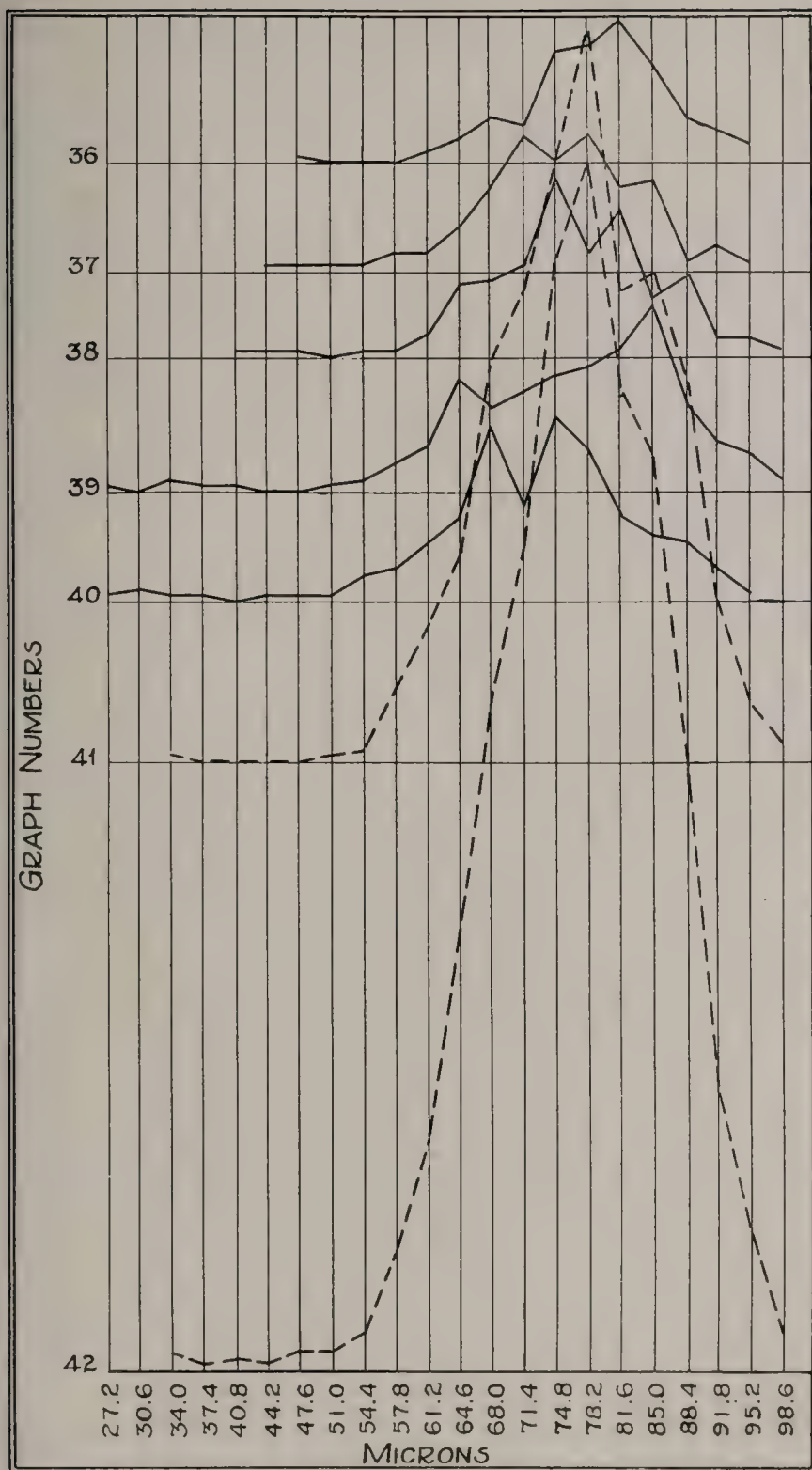


FIGURE I.

Graphs of conidial length of H. No. 2 (H. ravenelii).

Graph 43, Seymour and Earle, Economic Fungi, No. 399, Florida, 1890.

Graph 44, Ellis, North American Fungi, No. 368. North Carolina.

Graph 45, A. B. Seymour's specimen as grown by me on corn-meal agar.

Graph 46, deThümen, Mycotheca Universalis, No. 1468. Carolina, 1876.

Graph 47, A. B. Seymour's specimen from Louisiana, 1919.

Graph 48, Bartholomew, Fungi Columbiana, No. 3026. Nova Scotia, 1909.

Graph 49, Ravenel, Fungi Americani Exsiccati, No. 165. Florida.

Graph 50, Ellis and Everhart, Fungi Columbiana, No. 4633. Florida, 1914.

Graph 51, Ellis and Everhart, Fungi Columbiana, No. 465. Carolina, 1894.

Graph 52, Rabenhorst, Fungi Europei, No. 3082. Argentine, 1878, sample 1.

Graph 53, Rabenhorst, Fungi Europei, No. 3082a. Argentine, 1878, sample 2.

Graph	M	σ	CV
43	14.97 $\pm$.18	2.53 $\pm$.13	16.89 $\pm$.89
44	14.80 $\pm$.22	3.58 $\pm$.15	24.17 $\pm$ 1.73
45	14.79 $\pm$.14	2.27 $\pm$.10	15.34 $\pm$.69
46	14.49 $\pm$.19	2.19 $\pm$.16	15.11 $\pm$.97
47	14.38 $\pm$.16	2.38 $\pm$.11	16.54 $\pm$.84
48	14.35 $\pm$.22	3.02 $\pm$.15	21.04 $\pm$ 1.15
49	14.34 $\pm$.21	2.74 $\pm$.15	19.10 $\pm$ 1.18
50	13.98 $\pm$.20	2.82 $\pm$.14	20.15 $\pm$ 1.50
51	13.78 $\pm$.20	3.49 $\pm$.14	25.31 $\pm$ 1.08
52	13.02 $\pm$.20	3.16 $\pm$.14	24.25 $\pm$ 1.18
53	12.05 $\pm$.19	3.10 $\pm$.13	25.72 $\pm$ 1.22

FIGURE L

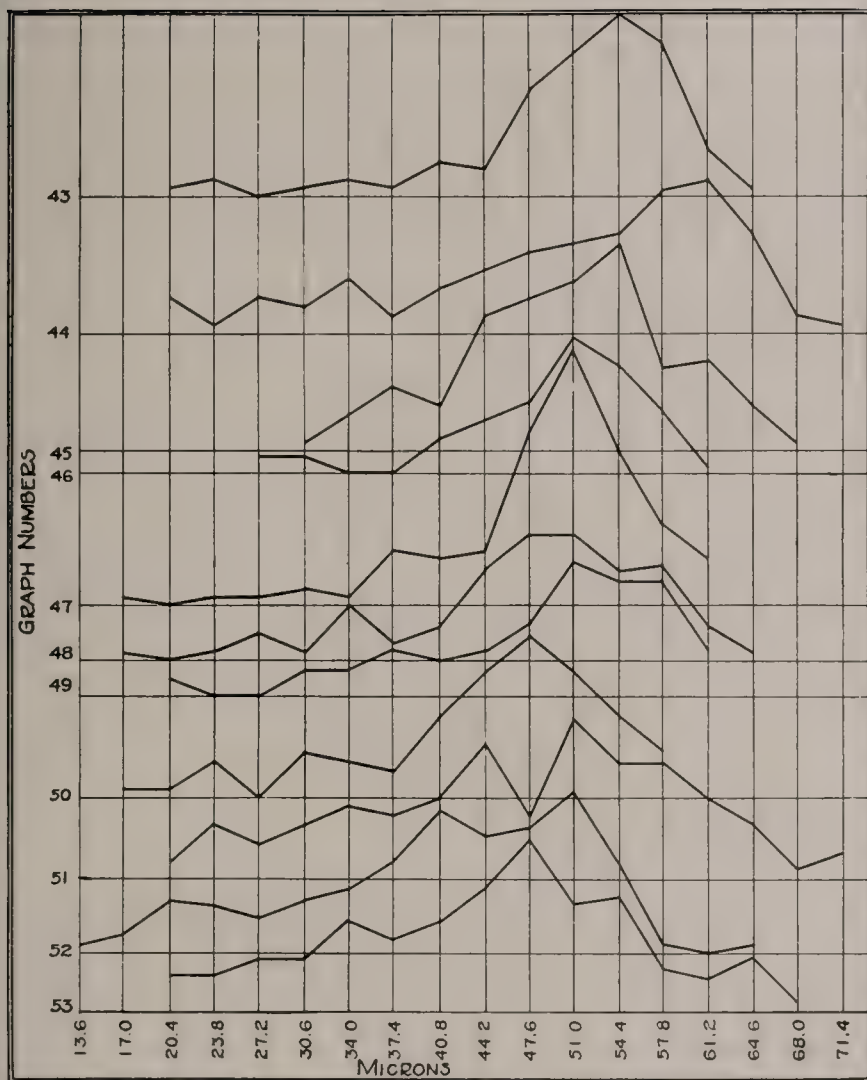


FIGURE M

Conidial length of H. No. 1 grown under standard conditions but on various cereal shoots: Graph 54, as grown on corn; Graph 55, as grown on rye; Graph 56, as grown on barley; Graph 57, as grown on wheat.

Graph	M	σ	CV
54	22.49 $\pm$.06	2.83 $\pm$.04	12.57 $\pm$.20
55	23.06 $\pm$.19	2.64 $\pm$.13	11.44 $\pm$.59
56	23.00 $\pm$.19	3.09 $\pm$.13	13.43 $\pm$.60
57	22.66 $\pm$.22	3.36 $\pm$.15	14.82 $\pm$.69

FIGURE M

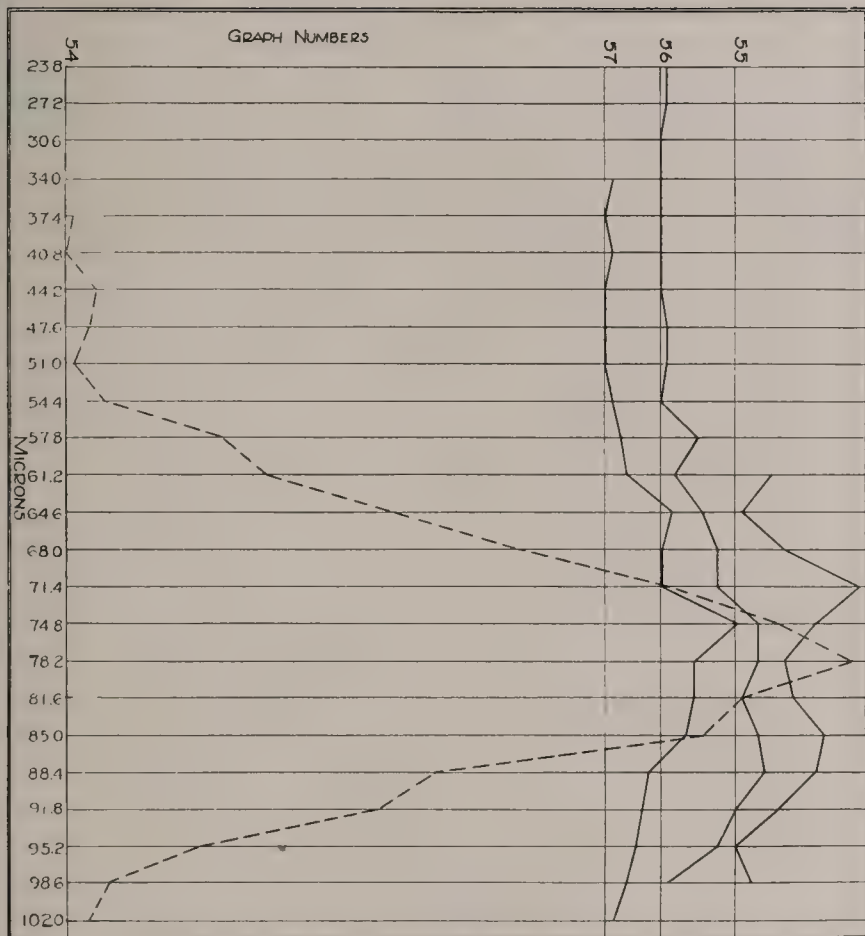


FIGURE N

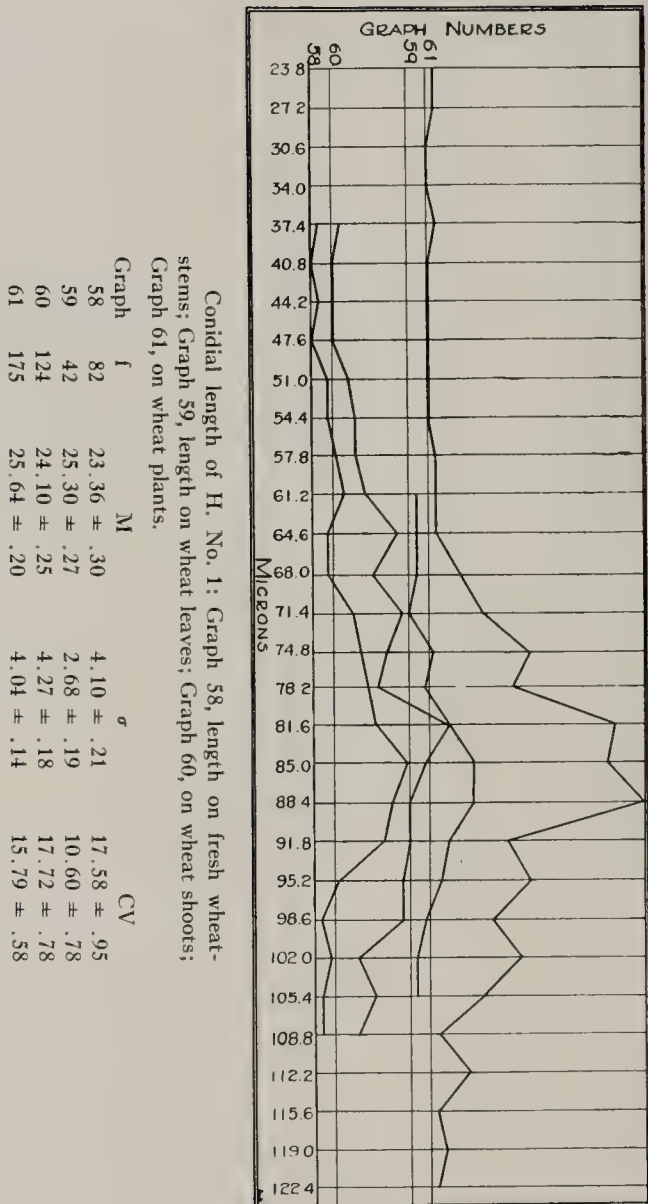
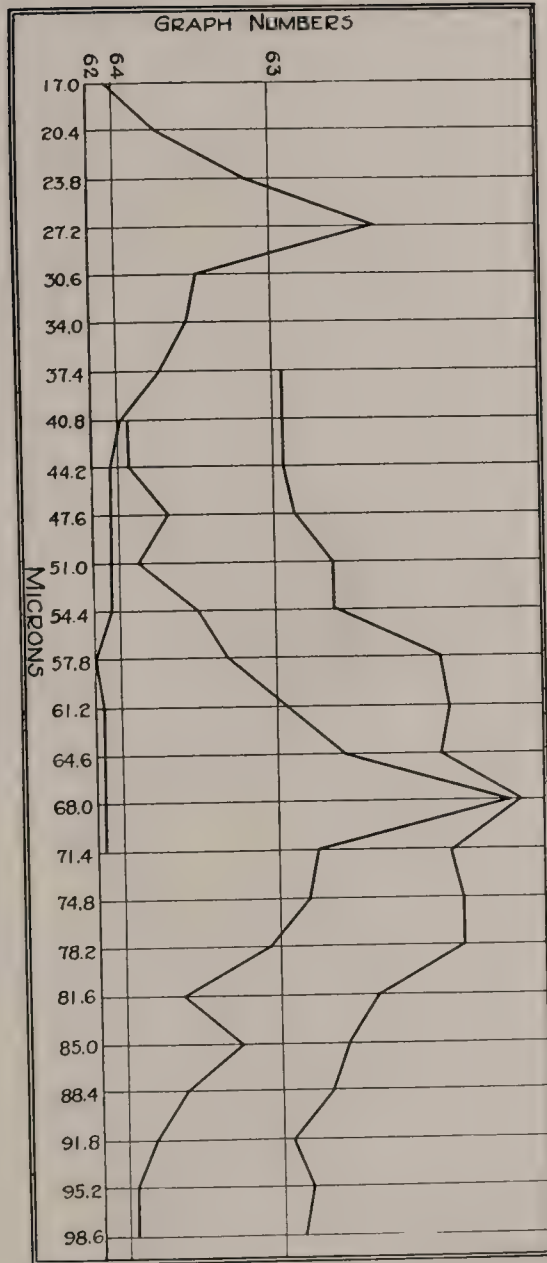


FIGURE O



Three graphs (62, 63, 64) of conidial length of H. No. 1: Graph 62, length of conidia in bank of same produced near edge of colony grown on corn-meal agar in Petri dish, but dried till growth had stopped; Graph 63, length on washed agar $\frac{3}{4}$, plus green-wheat agar $\frac{1}{4}$; Graph 64, on live wheat from rag doll.

Graph	f	M	σ	CV
62	95	8.95 $\pm$.18	2.68 $\pm$.13	29.99 $\pm$ 1.59
63	—	20.35 $\pm$.16	3.29 $\pm$.11	16.19 $\pm$.59
64	—	20.30 $\pm$.14	2.97 $\pm$.10	14.62 $\pm$.51

FIGURE P

Conidial length of M35, M36, and M40, with that of H. No. 1 for comparison: Graph 65, M35-1; Graph 66, M36-2; Graph 67, M40-2; Graph 68, H. No. 1.

Graph	f	M	σ	CV
65	179	16.80 $\pm$.18	3.75 $\pm$.13	22.35 $\pm$.83
66	156	22.31 $\pm$.16	3.14 $\pm$.12	14.09 $\pm$.54
67	97	17.70 $\pm$.17	2.51 $\pm$.12	14.19 $\pm$.70
68	123	23.21 $\pm$.15	2.36 $\pm$.10	10.02 $\pm$.46
	*1199	22.62 $\pm$.05	2.76 $\pm$.03	12.22 $\pm$.16

*H. No. 1 of Graph 42 (Fig. K). See also p. 170.

FIGURE P

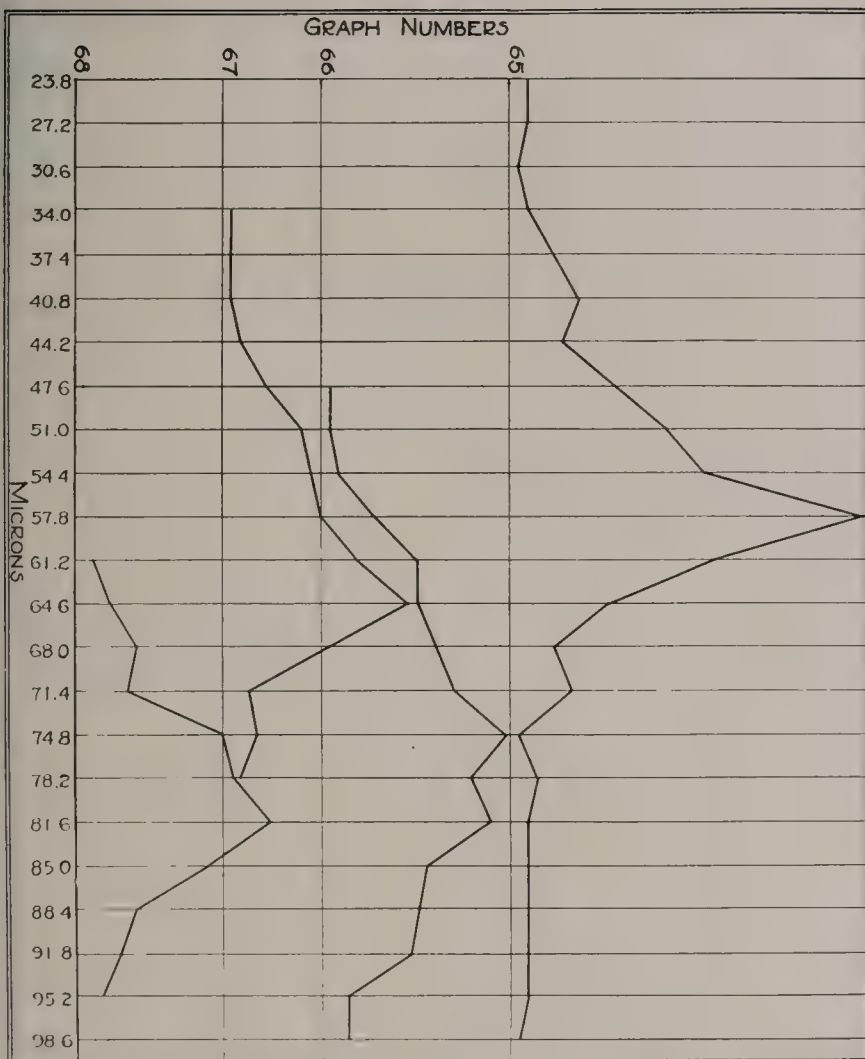


FIGURE Q

Graphs of conial breadth of saltants and originals under standard conditions: Graph 69, M1-5; Graph 70, M6-1; Graph 71, original from same plate as M6-1; Graph 72, M6-5, a week later; Graph 73, M8-3; Graph 74, original from same plate as M8-3; Graph 75, M8-7; Graph 76, M8-10; Graph 77, M36-2; Graph 78, H. No. 1.

Graph	f	M	σ	CV
69	25	$7.50 \pm .07$	$.52 \pm .05$	$7.05 \pm .67$
70	58	$6.29 \pm .07$	$.80 \pm .05$	$12.86 \pm .81$
71	72	$5.43 \pm .04$	$.59 \pm .03$	$10.99 \pm .62$
72	35	$7.22 \pm .06$	$.56 \pm .04$	$7.81 \pm .63$
73	37	$7.45 \pm .10$	$.91 \pm .07$	$12.30 \pm .97$
74	23	$5.54 \pm .07$	$.50 \pm .05$	$9.18 \pm .91$
75	67	$7.32 \pm .04$	$.58 \pm .03$	$8.04 \pm .46$
76	24	$7.10 \pm .06$	$.45 \pm .04$	$6.41 \pm .62$
77	33	$7.83 \pm .03$	$.31 \pm .02$	$4.05 \pm .33$
78	57	$6.03 \pm .04$	$.55 \pm .34$	$9.13 \pm .57$

FIGURE Q



FIGURE R

Graphs of conidial septation of saltants: Graph 79, M4-6; Graph 80, M5-5; Graph 81, M6-5; Graph 82, M37-2; Graph 83, M1-5; Graph 84, M12-3; Graph 85, M12-4.

Graph	f	M	σ	CV
79	32	7.09 $\pm$.14	1.23 $\pm$.10	17.39 $\pm$ 1.51
80	25	7.28 $\pm$.18	1.37 $\pm$.13	18.84 $\pm$ 1.86
81	49	7.28 $\pm$.13	1.41 $\pm$.09	19.41 $\pm$ 1.37
82	55	7.38 $\pm$.11	1.30 $\pm$.08	17.61 $\pm$ 1.16
83	45	5.44 $\pm$.13	1.32 $\pm$.09	24.35 $\pm$ 1.83
84	61	5.11 $\pm$.12	1.48 $\pm$.09	28.99 $\pm$ 1.91
85	81	7.43 $\pm$.10	1.45 $\pm$.07	19.57 $\pm$ 1.07

FIGURE R

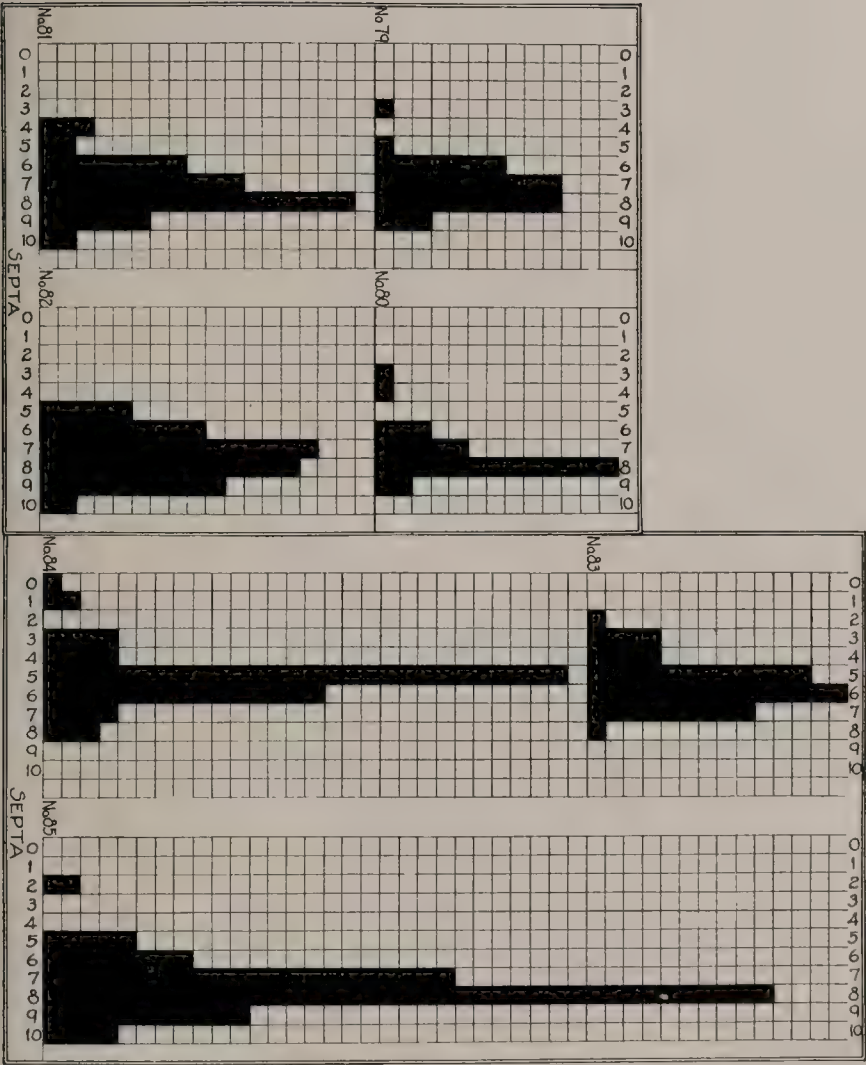


FIGURE S

Graph of conidial length of H. No. 11.

Graph	f	M	σ	CV
86	134	18.85 $\pm$.20	3.58 $\pm$.14	19.03 $\pm$.81

FIGURE S

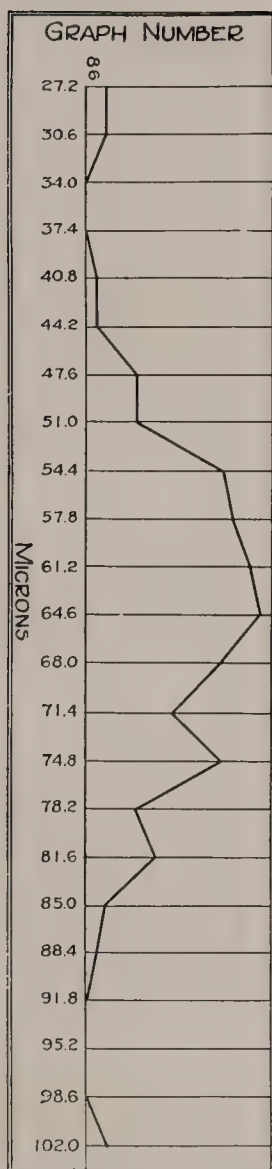


FIGURE T

Graphs of conical septation of several *Helminthosporium* under standard conditions: Graph 87, H. No. 11; Graph 88, H. No. 20; Graph 89, H. No. 13; Graph 90, H. No. 14; Graph 91, H. No. 15; Graph 92, H. No. 16.

Graph	f	M	σ	CV
87	30	6.13 $\pm$.14	1.20 $\pm$.10	19.62 $\pm$ 1.77
88	48	6.10 $\pm$.04	.50 $\pm$.03	8.35 $\pm$.57
89	90	7.90 $\pm$.07	1.02 $\pm$.05	13.01 $\pm$.66
90	83	6.95 $\pm$.10	1.36 $\pm$.07	19.58 $\pm$ 1.06
91	81	7.11 $\pm$.08	1.19 $\pm$.16	16.82 $\pm$.91
92	57	7.33 $\pm$.07	.86 $\pm$.05	11.79 $\pm$.75

FIGURE T

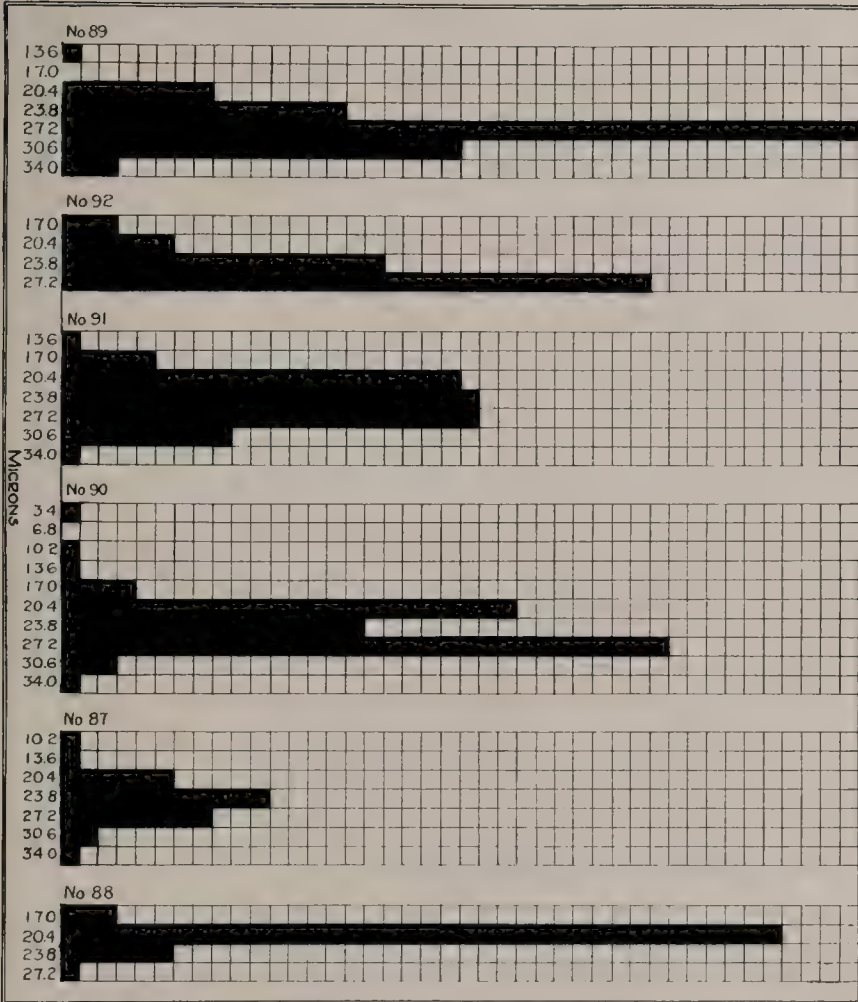


FIGURE U

Graphs of conidial length of several *Helminthosporium* under standard conditions: Graph 93, H. No. 14; Graph 94, H. No. 13; Graph 95, H. No. 15; Graph 96, H. No. 16; Graph 97, H. No. 17; Graph 98, H. No. 18; Graph 99, H. No. 19; Graph 100, H. No. 20.

Graph	f	M	σ	CV
93	404	22.04 $\pm$.10	3.03 $\pm$.07	13.76 $\pm$.33
94	597	24.78 $\pm$.09	3.53 $\pm$.06	14.24 $\pm$.28
95	461	22.54 $\pm$.10	3.49 $\pm$.07	15.51 $\pm$.35
96	445	23.75 $\pm$.12	3.80 $\pm$.08	16.03 $\pm$.37
97	252	24.39 $\pm$.15	3.63 $\pm$.10	14.88 $\pm$.45
98	97	23.03 $\pm$.28	4.10 $\pm$.19	17.81 $\pm$.88
99	205	24.59 $\pm$.19	4.15 $\pm$.13	16.89 $\pm$.57
100	315	18.84 $\pm$.12	3.30 $\pm$.08	17.53 $\pm$.48

FIGURE U

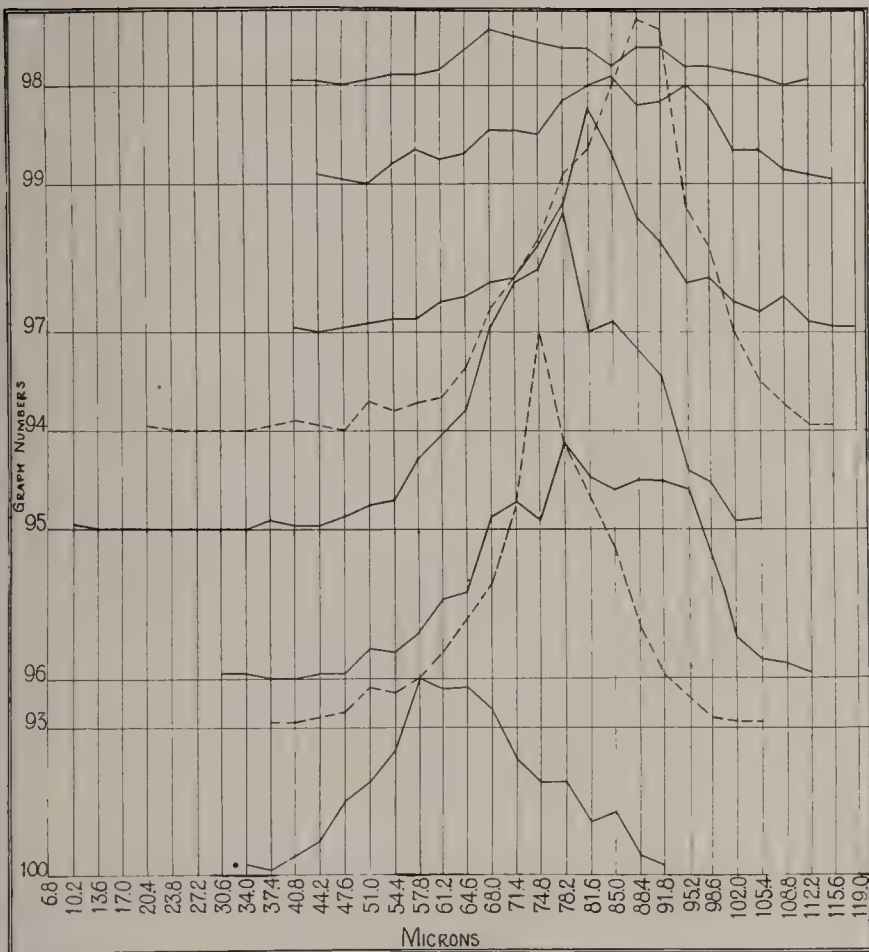


FIGURE V

Graphs of conidial breadth of several *Helminthosporium* under standard conditions: Graph 101, H. No. 11; Graph 102, H. No. 20; Graph 103, H. No. 13; Graph 104, H. No. 14; Graph 105, H. No. 15; Graph 106, H. No. 16.

Graph	f	M	σ	CV
101	39	5.19 $\pm$.04	.40 $\pm$.03	7.74 $\pm$.59
102	58	5.11 $\pm$.14	.52 $\pm$.03	10.27 $\pm$.65
103	79	5.97 $\pm$.08	1.06 $\pm$.05	17.85 $\pm$.98
104	32	5.59 $\pm$.08	.74 $\pm$.06	13.30 $\pm$ 1.14
105	88	5.39 $\pm$.04	.56 $\pm$.02	10.50 $\pm$.53
106	45	5.88 $\pm$.05	.56 $\pm$.04	9.61 $\pm$.68

FIGURE V

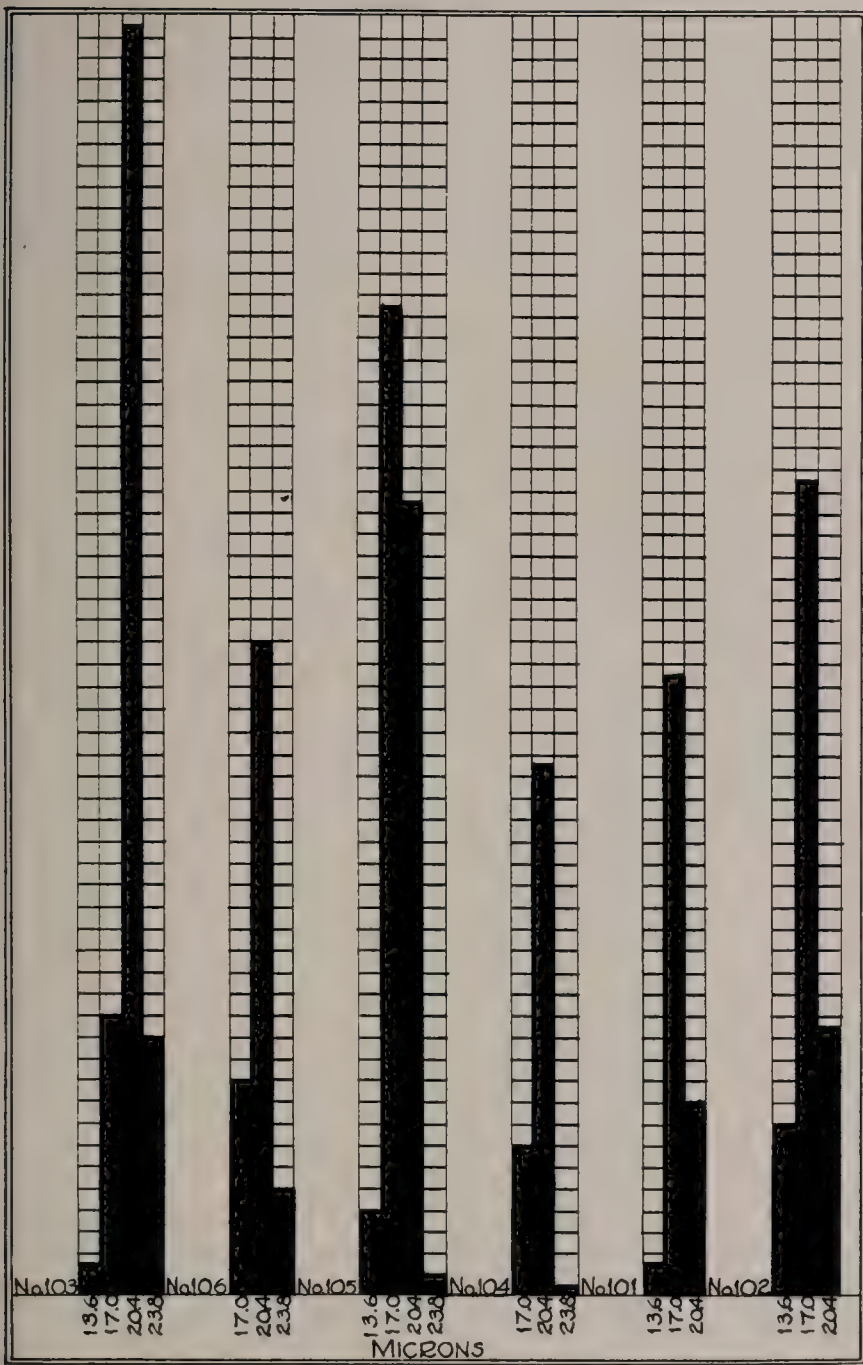


FIGURE W

Graphs of conidial length—under standard conditions—of H. No. 1a (107); H. No. 1b (108); H. No. 1c (109); H. No. 1d (110).

Graph	f	M	σ	CV
107	111	21.20 $\pm$.17	2.66 $\pm$.12	12.58 $\pm$.57
108	130	21.52 $\pm$.16	2.86 $\pm$.11	13.30 $\pm$.56
109	160	20.09 $\pm$.12	2.29 $\pm$.08	11.42 $\pm$.43
110	153	19.26 $\pm$.11	2.12 $\pm$.08	11.03 $\pm$.43

FIGURE W

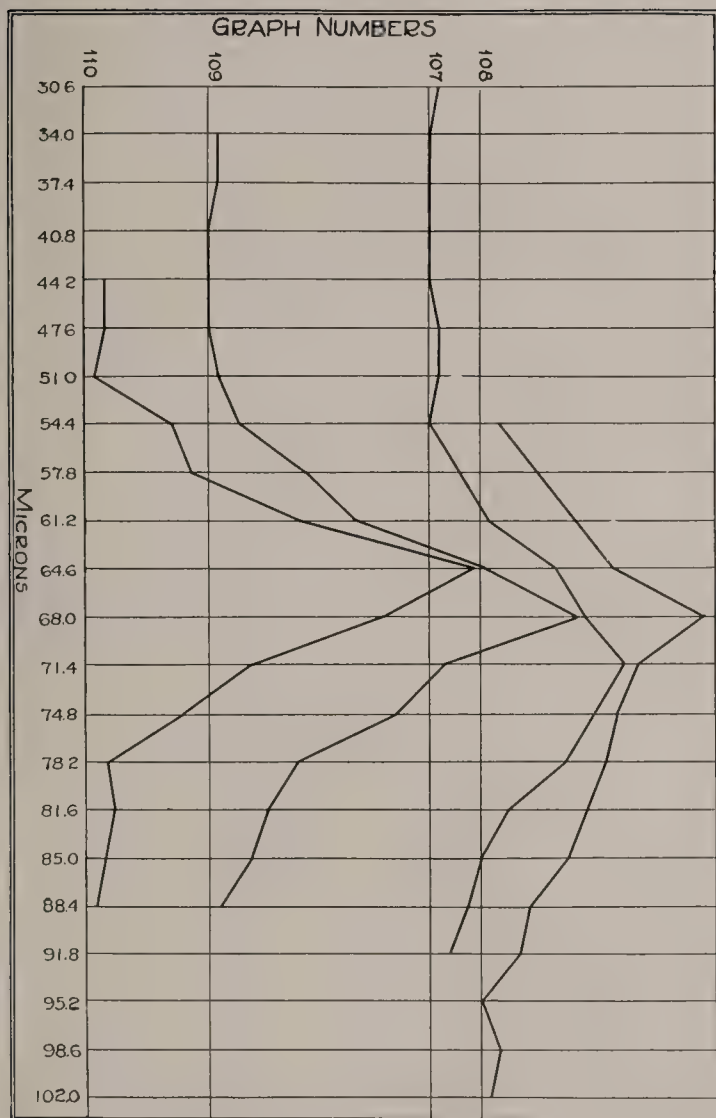


FIGURE X

Graphs of conidial septation—under standard conditions—of H. No. 1*a* (111); H. No. 1*b* (112); H. No. 1*c* (113).

Graph	f	M	σ	CV
111	49	6.71 $\pm$.10	1.12 $\pm$.07	16.75 $\pm$ 1.17
112	65	6.61 $\pm$.09	1.15 $\pm$.06	17.52 $\pm$ 1.08
113	17	6.64 $\pm$.09	.58 $\pm$.06	8.85 $\pm$ 1.02

FIGURE X

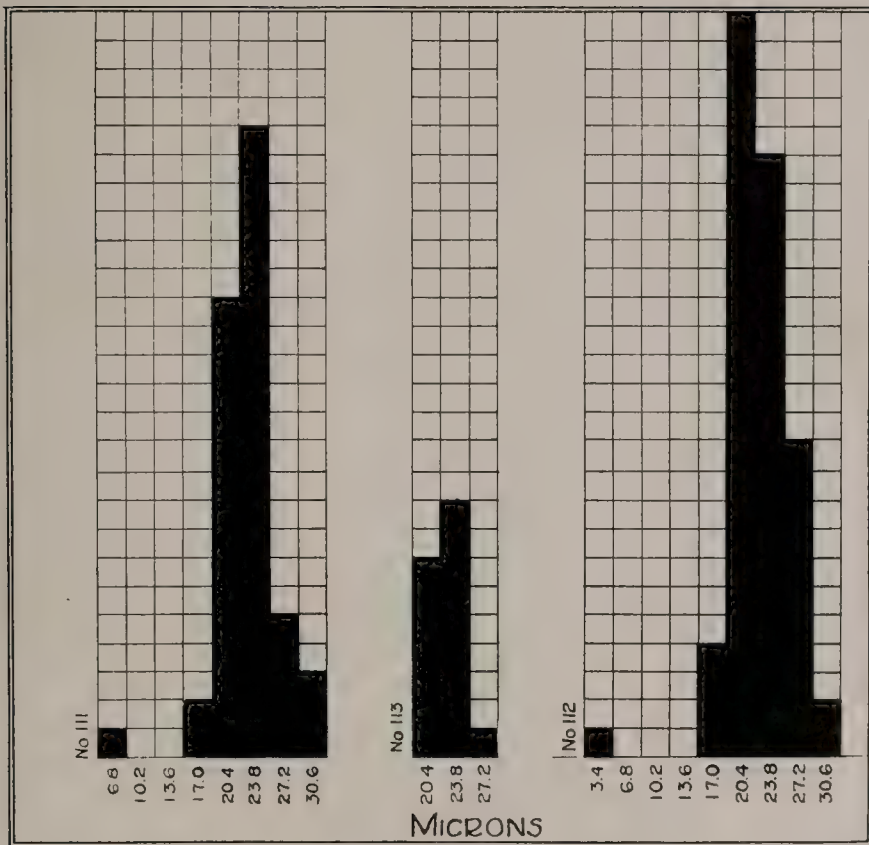


FIGURE Y

Saltant	Graph	f	M	σ	CV
M1-5	114	160	23.40 $\pm$.18	3.53 $\pm$.13	15.11 $\pm$.58
M2-4	115	154	21.77 $\pm$.17	3.17 $\pm$.12	14.56 $\pm$.57
M3-4	116	131	22.66 $\pm$.20	3.50 $\pm$.14	15.48 $\pm$.66
M4-6	117	168	22.72 $\pm$.21	4.04 $\pm$.14	17.80 $\pm$.67
M5-5	118	145	23.72 $\pm$.19	3.52 $\pm$.13	14.86 $\pm$.60
M6-5	119	166	23.65 $\pm$.20	3.85 $\pm$.14	16.28 $\pm$.61
M8-8	120	156	23.92 $\pm$.18	3.38 $\pm$.12	14.35 $\pm$.55
M12-3	121	148	23.64 $\pm$.20	3.73 $\pm$.14	15.81 $\pm$.63
M13-3	122	173	22.73 $\pm$.18	3.61 $\pm$.13	15.90 $\pm$.69
M14-3	123	126	22.32 $\pm$.17	2.98 $\pm$.12	13.37 $\pm$.57
M15-3	124	134	23.51 $\pm$.20	3.51 $\pm$.14	14.93 $\pm$.62
M36-2	125	156	22.31 $\pm$.16	3.14 $\pm$.12	14.09 $\pm$.54
M37-2	126	131	22.03 $\pm$.21	3.64 $\pm$.15	16.55 $\pm$.70
M32-2	127	86	23.00 $\pm$.16	2.33 $\pm$.12	10.14 $\pm$.52
M33-2	128	155	22.37 $\pm$.16	3.02 $\pm$.11	13.52 $\pm$.52
M40-2	129	97	17.70 $\pm$.17	2.51 $\pm$.12	14.19 $\pm$.70
M41-2	130	148	22.92 $\pm$.19	3.45 $\pm$.13	15.05 $\pm$.60
M42-2	131	125	22.36 $\pm$.21	3.53 $\pm$.15	15.81 $\pm$.69
M43-2	132	139	22.00 $\pm$.19	3.36 $\pm$.13	15.29 $\pm$.63
M44-2	133	134	22.18 $\pm$.15	2.72 $\pm$.11	12.27 $\pm$.51
M45-2	134	142	22.88 $\pm$.21	3.76 $\pm$.15	16.43 $\pm$.67
M46-2	135	158	22.84 $\pm$.17	3.34 $\pm$.12	14.66 $\pm$.56
M47-2	136	112	23.53 $\pm$.22	3.56 $\pm$.16	15.12 $\pm$.69
M48-2	137	146	22.00 $\pm$.16	3.02 $\pm$.11	13.78 $\pm$.55
M17-3	138	128	22.56 $\pm$.14	2.38 $\pm$.10	10.56 $\pm$.45

FIGURE Y

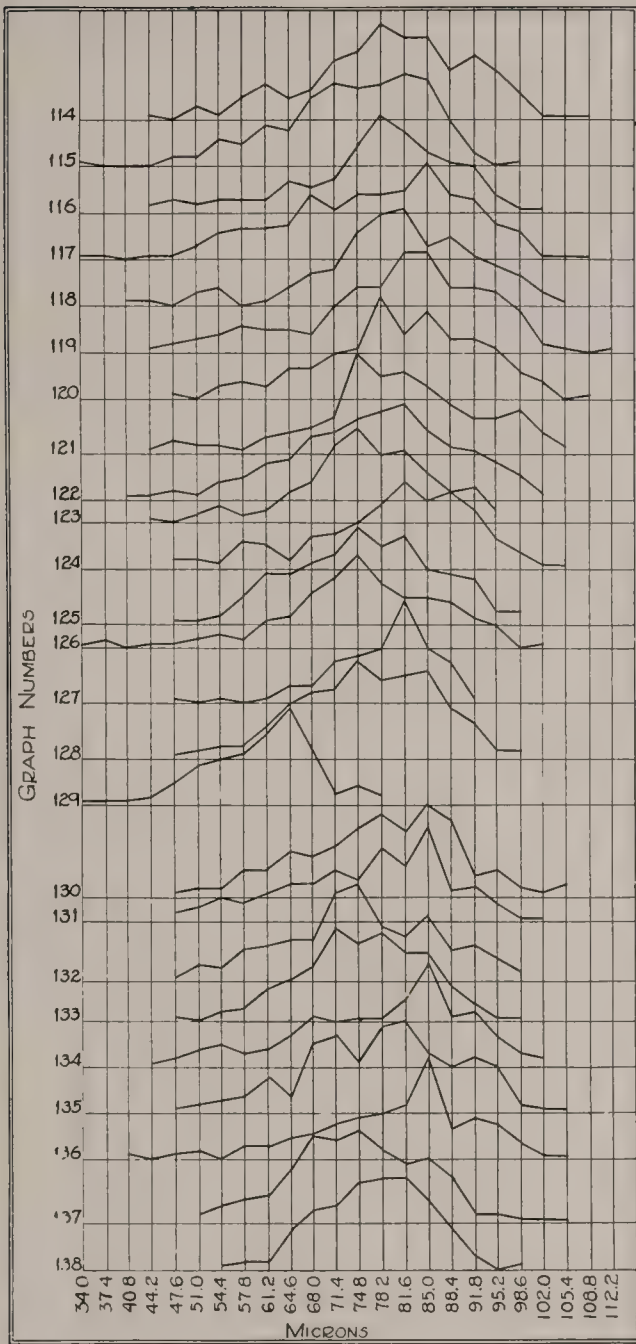
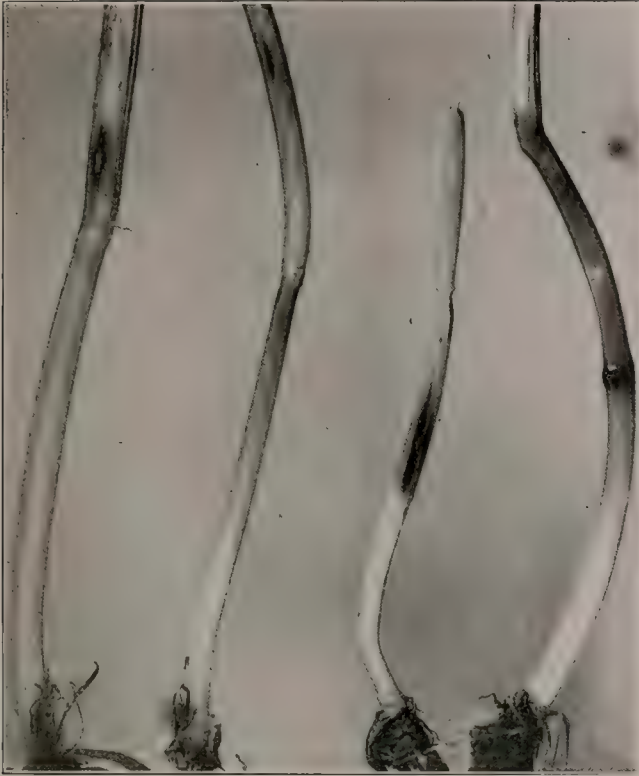


PLATE VII



Several wheat stems showing characteristic diseased spots;
also diseased portion at the node in one shoot.

PLATE VIII



Diseased plant, showing numerous dead leaves and leaf-sheaths, also more than a dozen new shoots issuing from below the diseased portions. These shoots varied in height from a few millimeters to several centimeters.

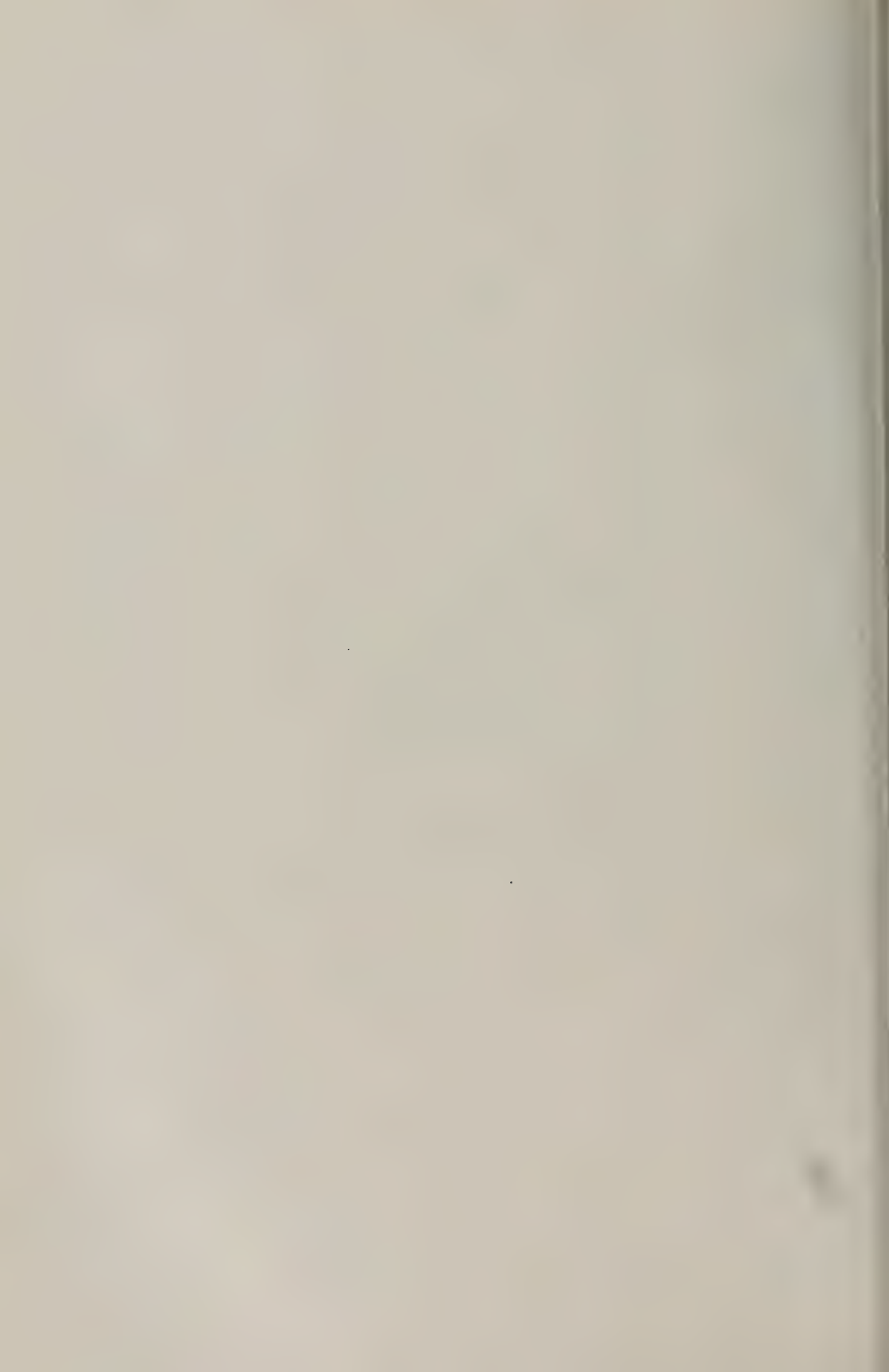
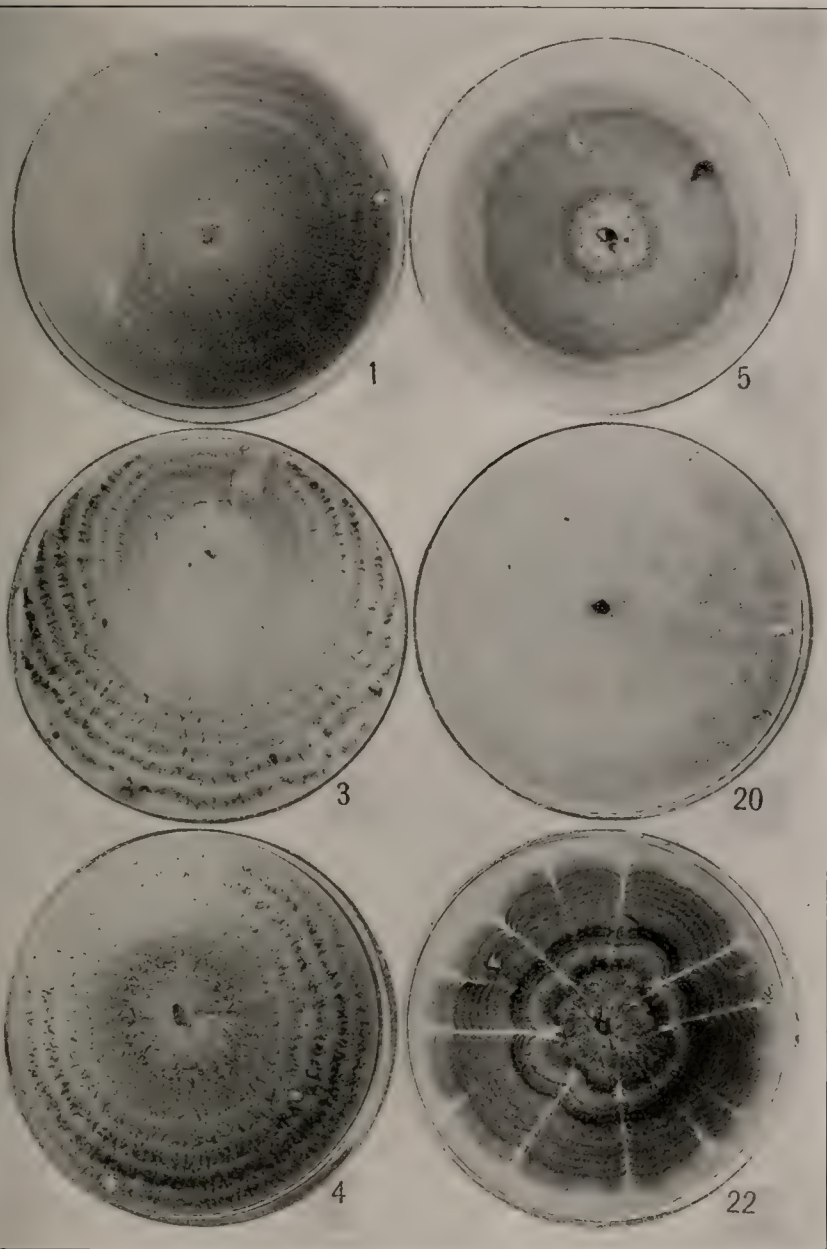
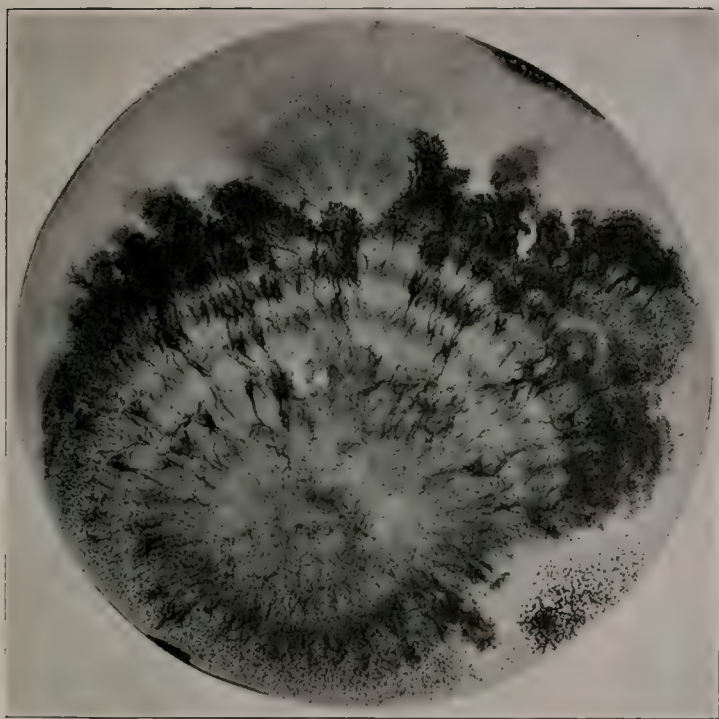


PLATE IX



H. Nos. 1, 3, 4, 5, 20, and 22, growing on corn-meal agar.

PLATE X



H. No. 36, showing very floccose mycelium.

PLATE XI

H. No. 3 (left) and No. 1 (right) as grown in Piorkowski-flask culture.

PLATE XI

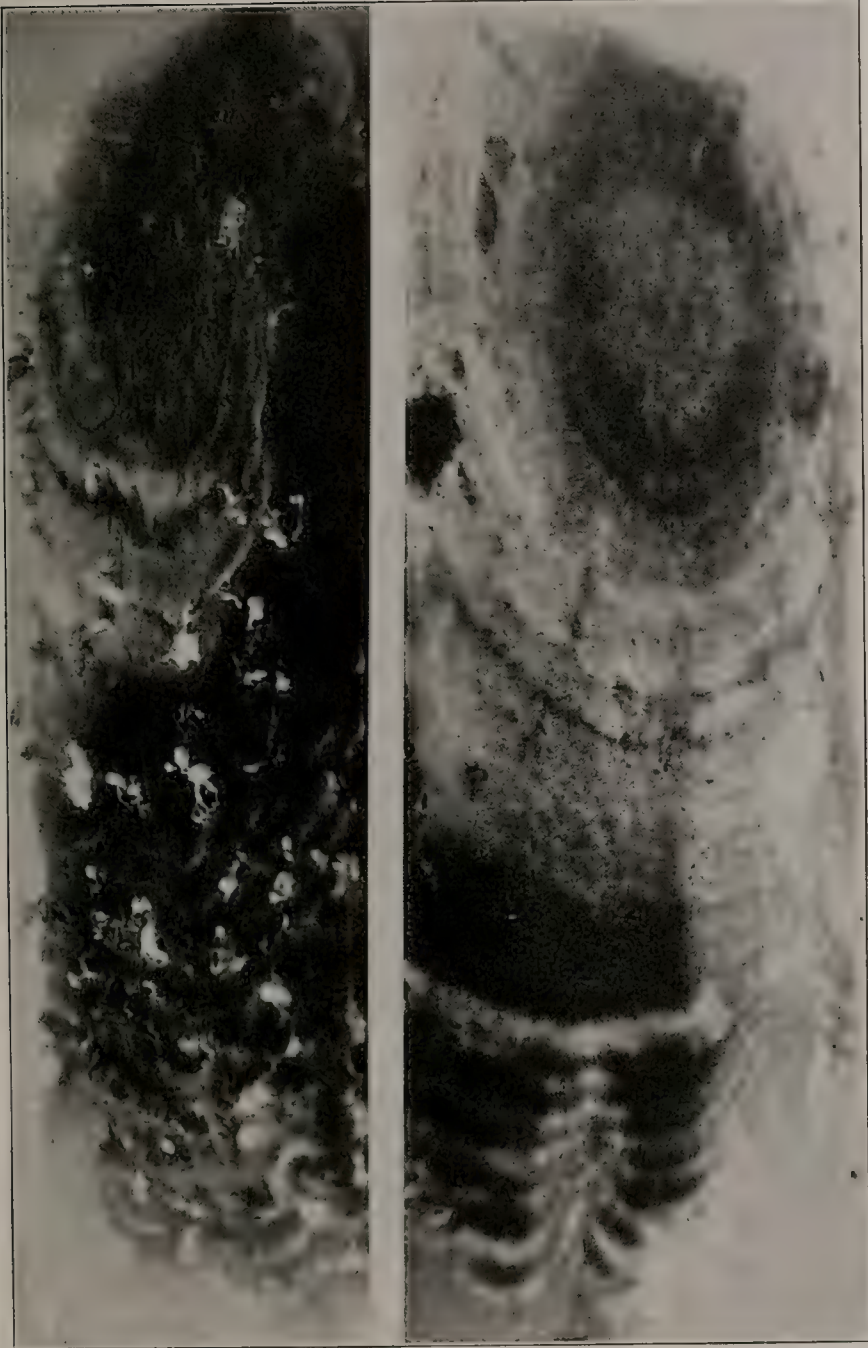


PLATE XII

H. No. 1 as grown in Kolle-flask culture.

PLATE XII



PLATE XIII

H, No. 3 as grown in Kōlle-flask culture.

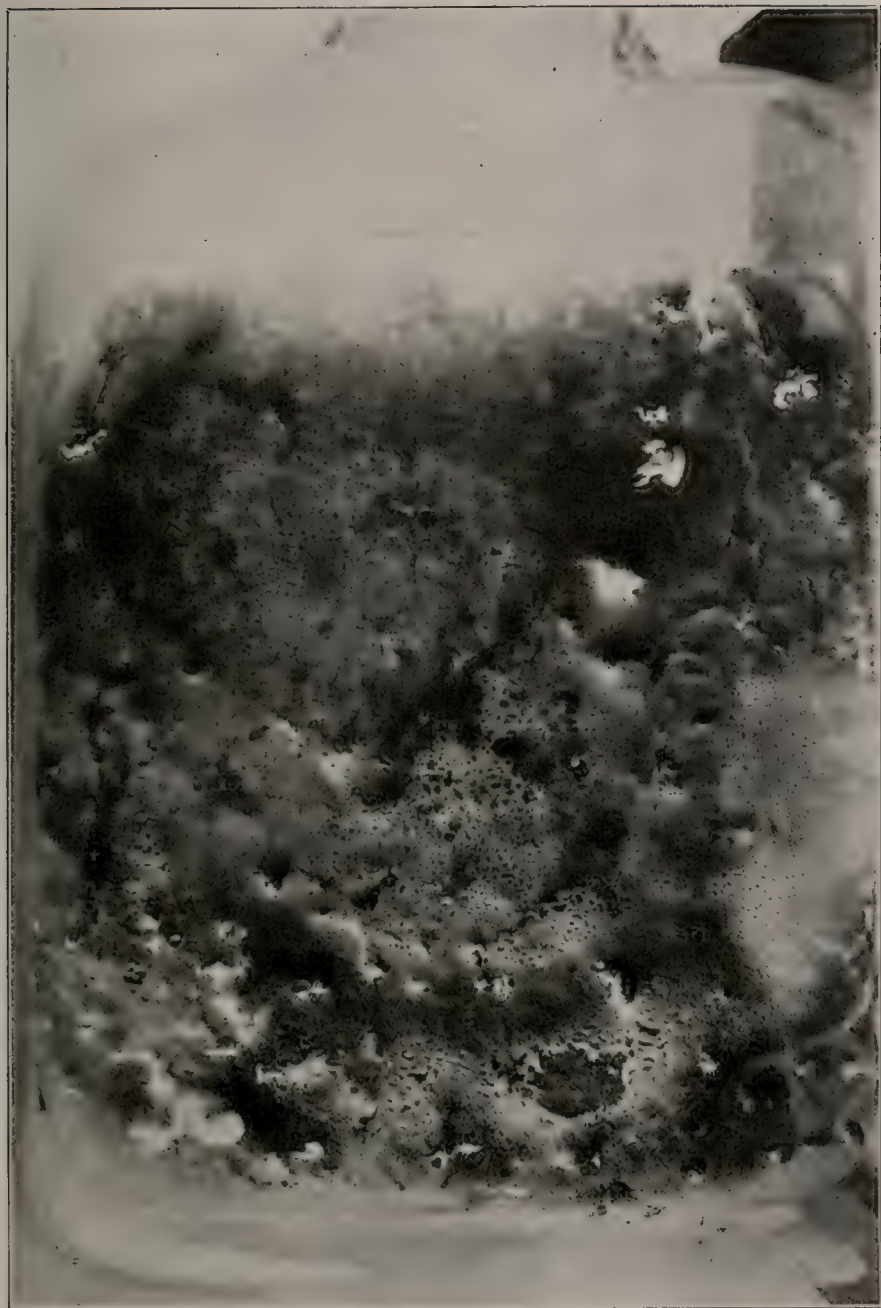
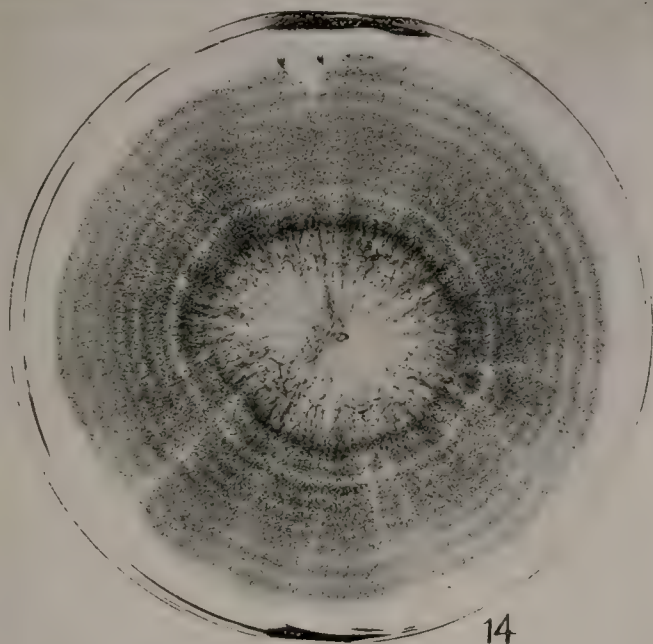


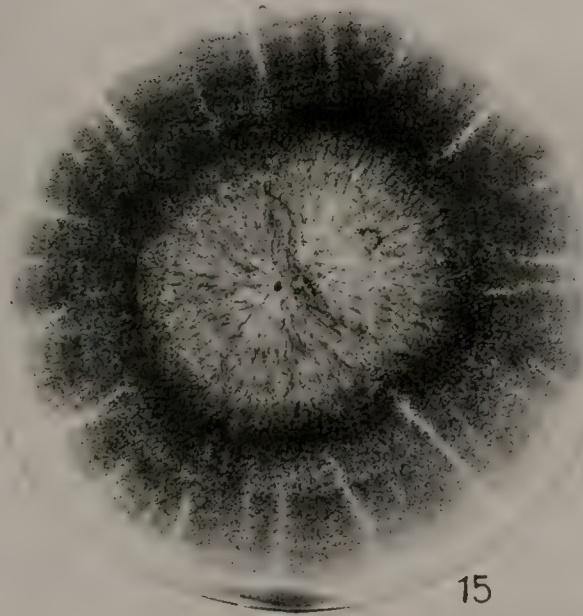
PLATE XIV

Petri-dish cultures of H. No. 1 on different amounts of agar: 14, on 12 c.c.;
15, on 30 c.c.

PLATE XIV



14



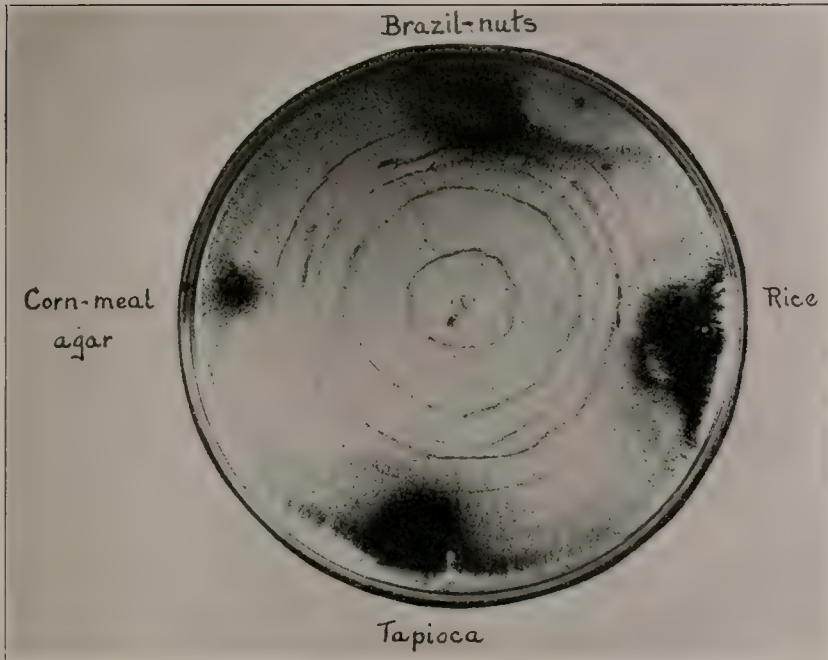
15

PLATE XV



H. No. 1 growing in tubes of rice with different amounts of water.
Note abundance of sclerotia in the drier tubes at the left.

PLATE XVI



H. No. 1 grown on washed agar with nutrients added as indicated—
fragments of Brazil-nuts, rice, tapioca, and corn-meal agar. (Circles
indicate approximate limits of growth at various periods.)

PLATE XVII



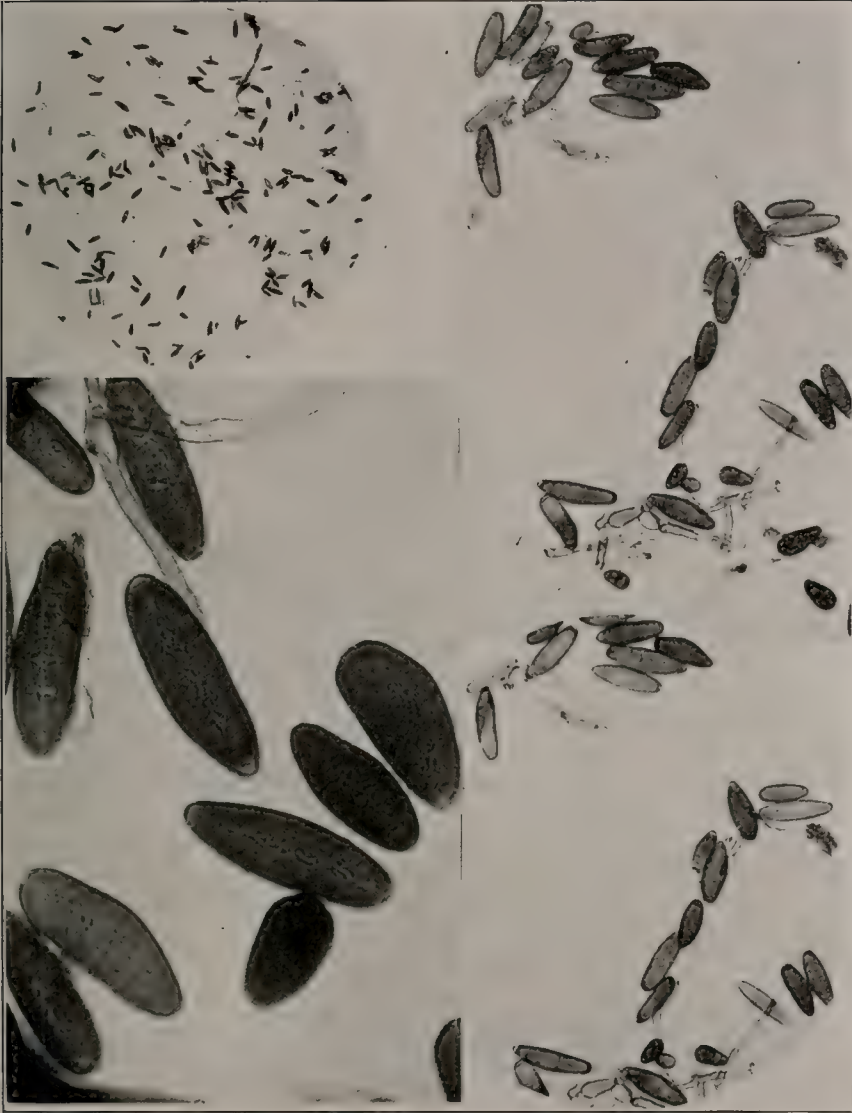
Photomicrographs of H. No. 1, showing attachment
of conidia to conidophores.

PLATE XVIII



Photomicrographs of H. No. 1, showing the fragile nature of the outer brown spore-wall and the gelatinous texture of the hyaline mass enclosed.
(Three different magnifications.)

PLATE XIX



Photomicrographs of H. No. 1, showing conidia under different magnifications.

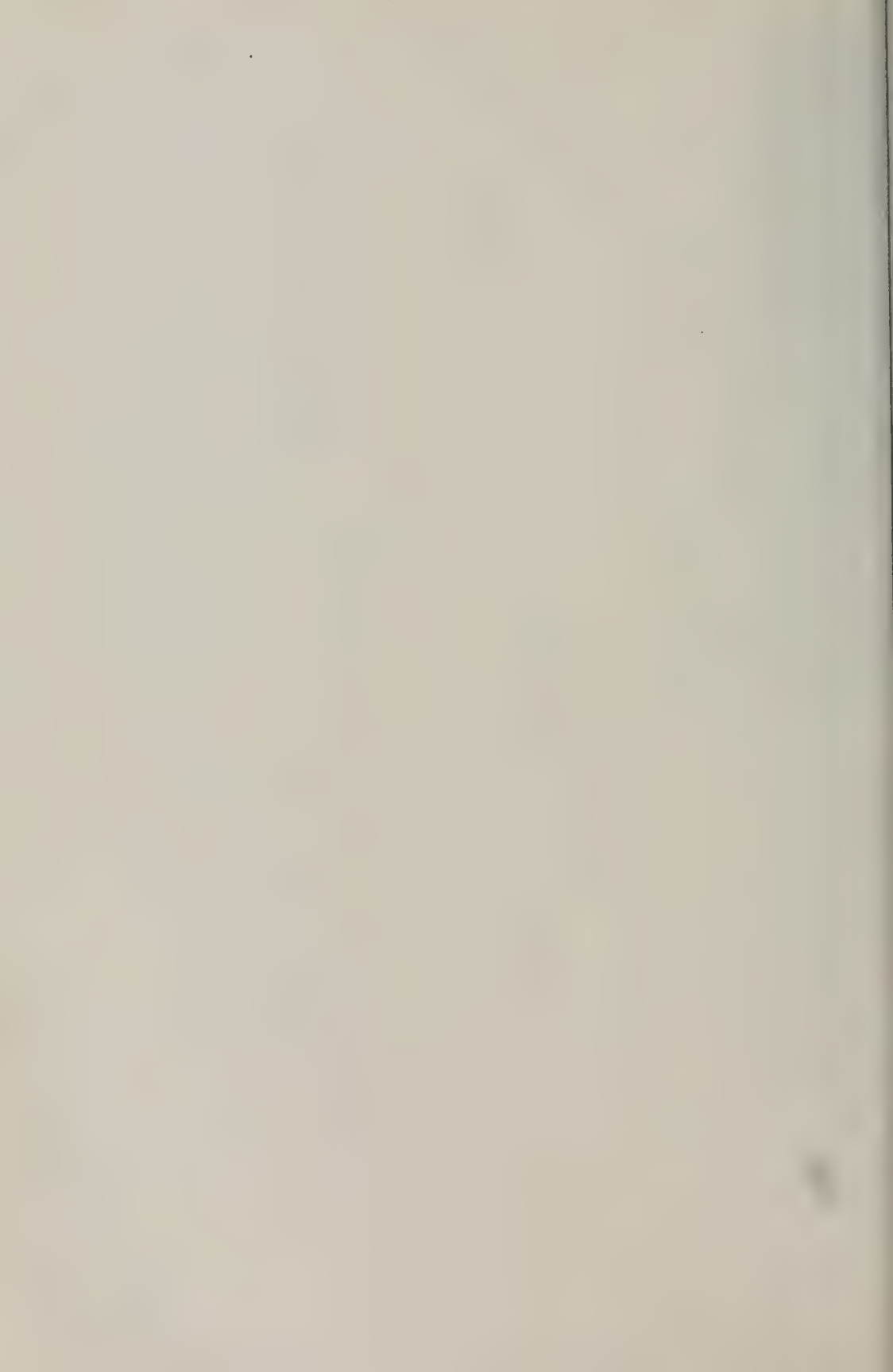
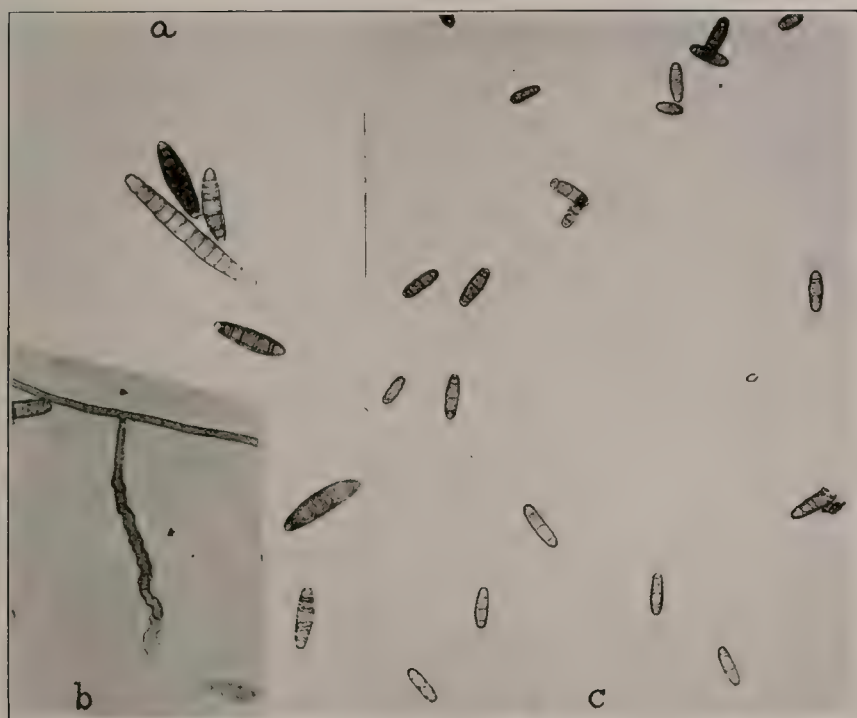


PLATE XX



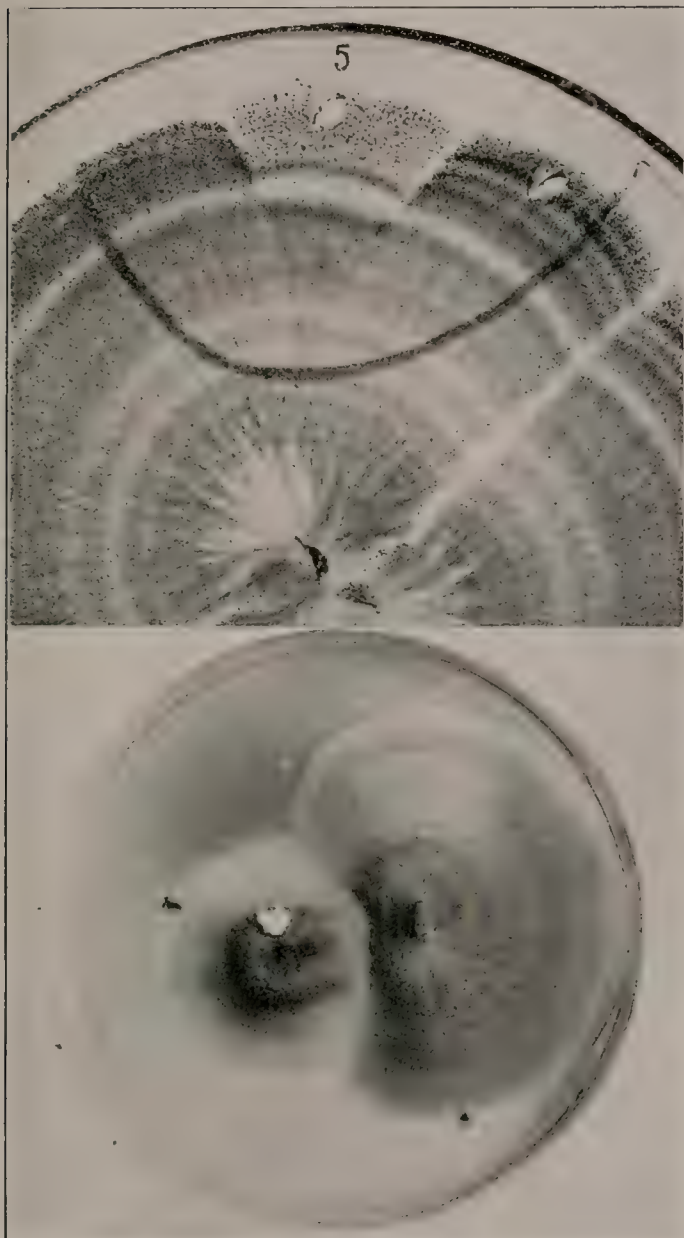
Photomicrograph of conidia of *H. ravenelii*.

PLATE XXI



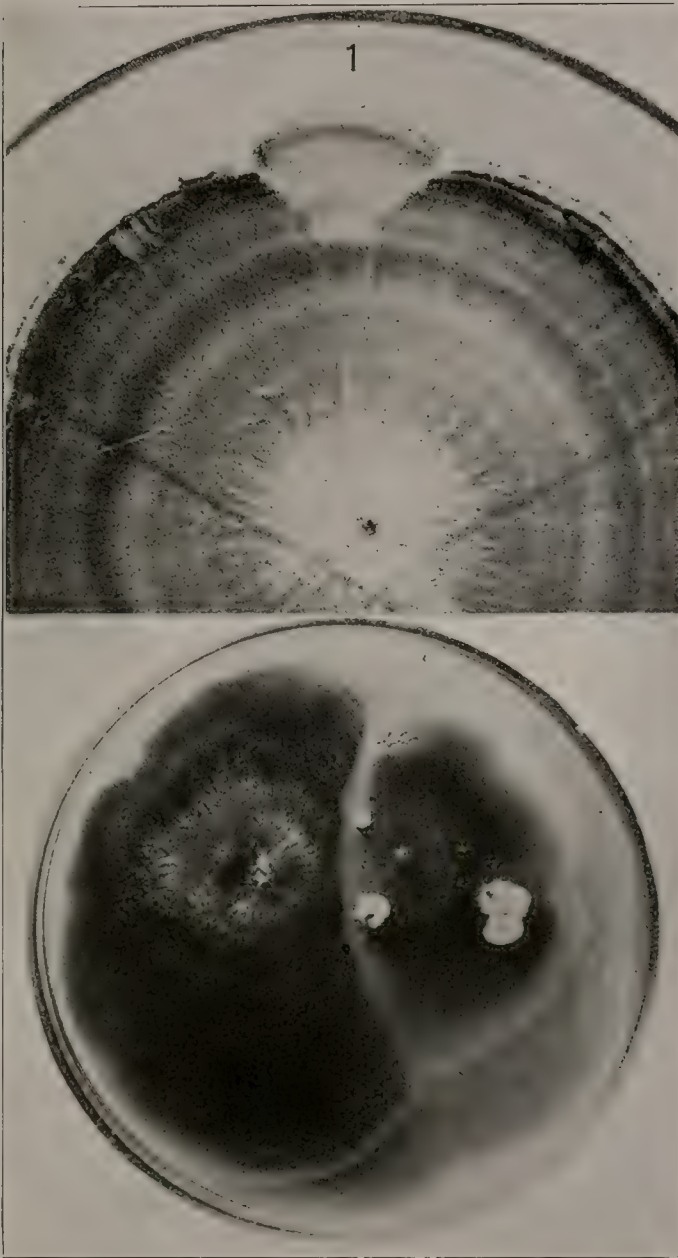
Conidia (*a*) of H. No. 36, showing variation in size and shape;
b and *c*, conidia and a conidiophore of H. No. 39.

PLATE XXII



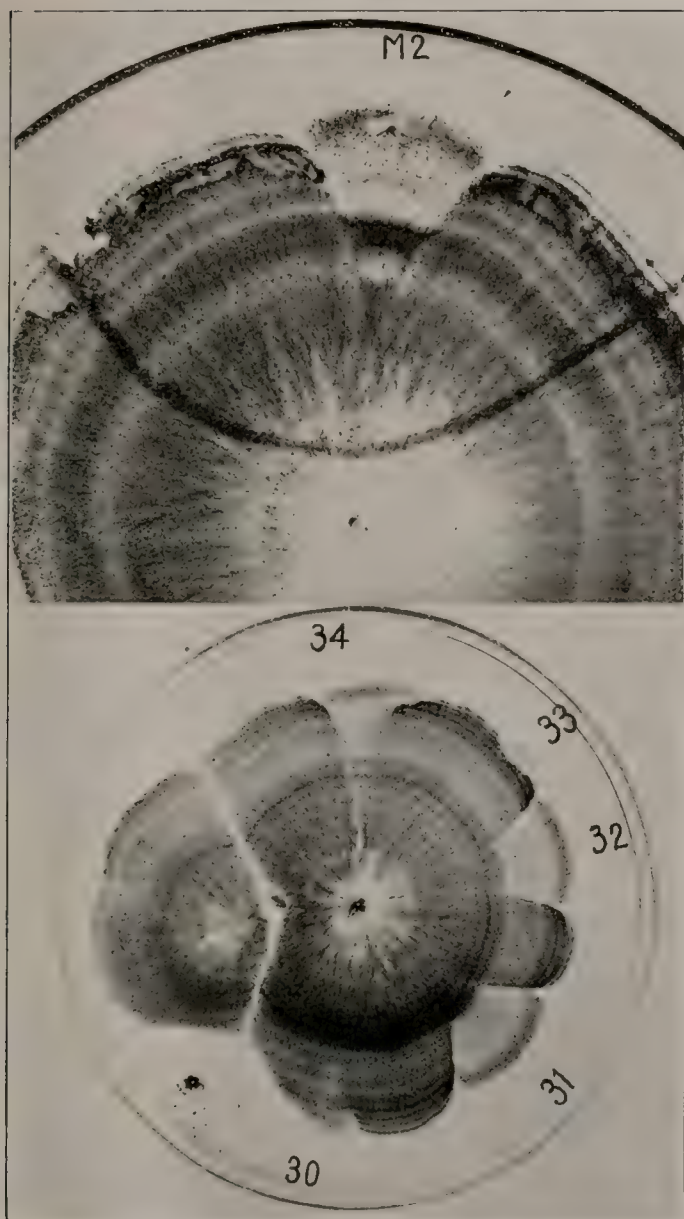
Two saltants: upper one showing origin of M5; lower one showing a white clump and slow growth.

PLATE XXIII



Two saltants: upper one showing origin of M1; lower one of slow growth and bearing clumps.

PLATE XXIV



Upper figure showing origin of M2; lower figure
showing origin of M30-M34.

PLATE XXV

Saltants growing with their respective originals.

PLATE XXV

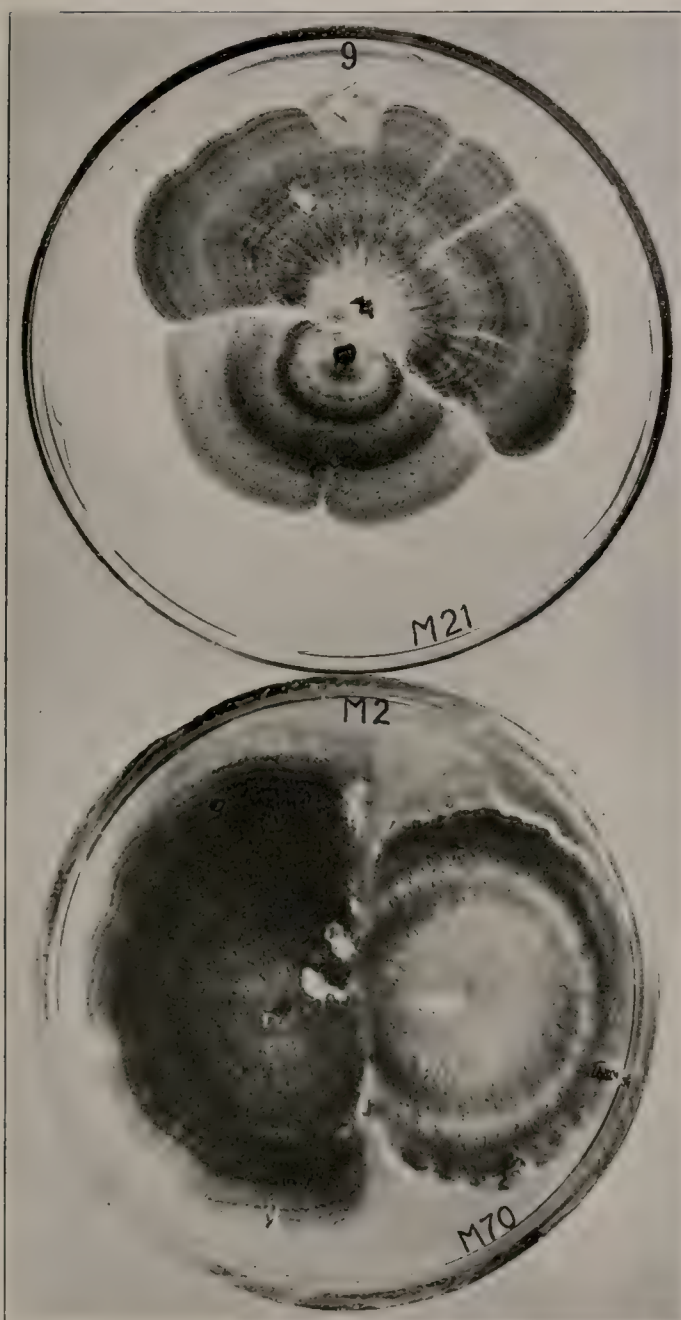


PLATE XXVI

Photomicrographs (same scale) of conidia of several Helminthosporiums:
a, H. No. 1; *b*, M6; *c*, M35; *d*, H. 20.

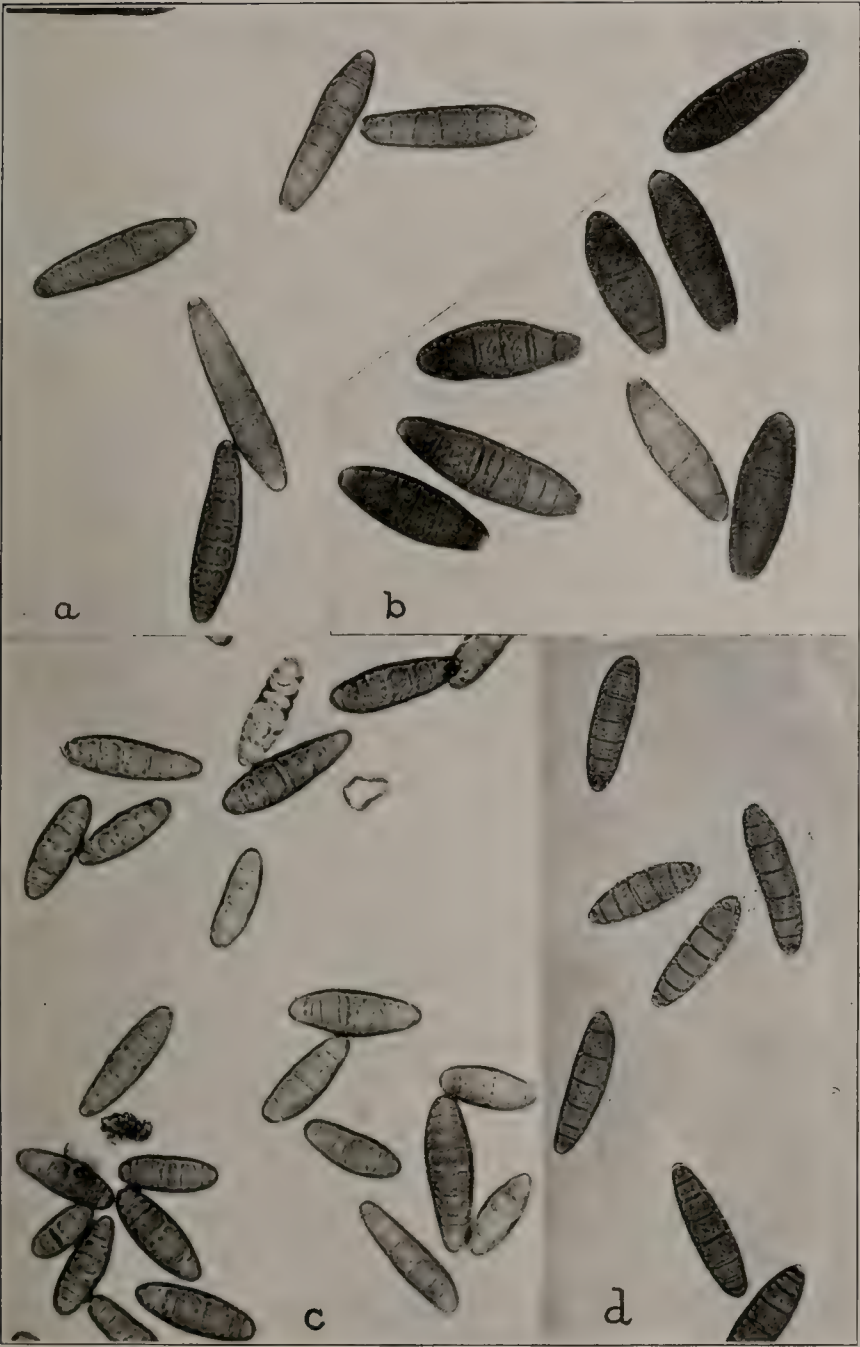


PLATE XXVII



Saltants growing with their respective originals.

PLATE XXVIII



M34, characterized by abundance of sclerotia and white mycelial clumps,
the latter a constant character of this saltant.

PLATE XXIX

Above, H. No. 1 wounded by hot wire at points shown;
below, H. No. 1, with H. No. 1 implanted at various distances
within and without the colony.

PLATE XXIX

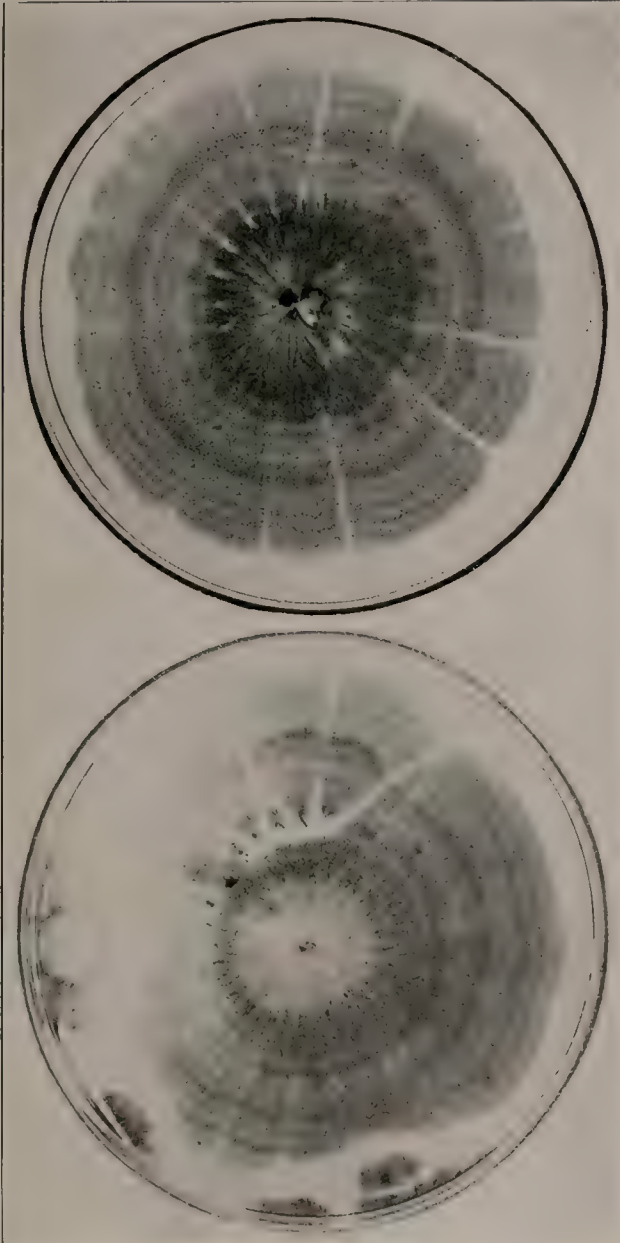


PLATE XXX

Above, two implants of H. No. 1—one of them the origin of M70—in H. No. 1 colony, showing some white floccose aerial mycelium; below, M26, with origins of M53, M56, and M57.

PLATE XXX

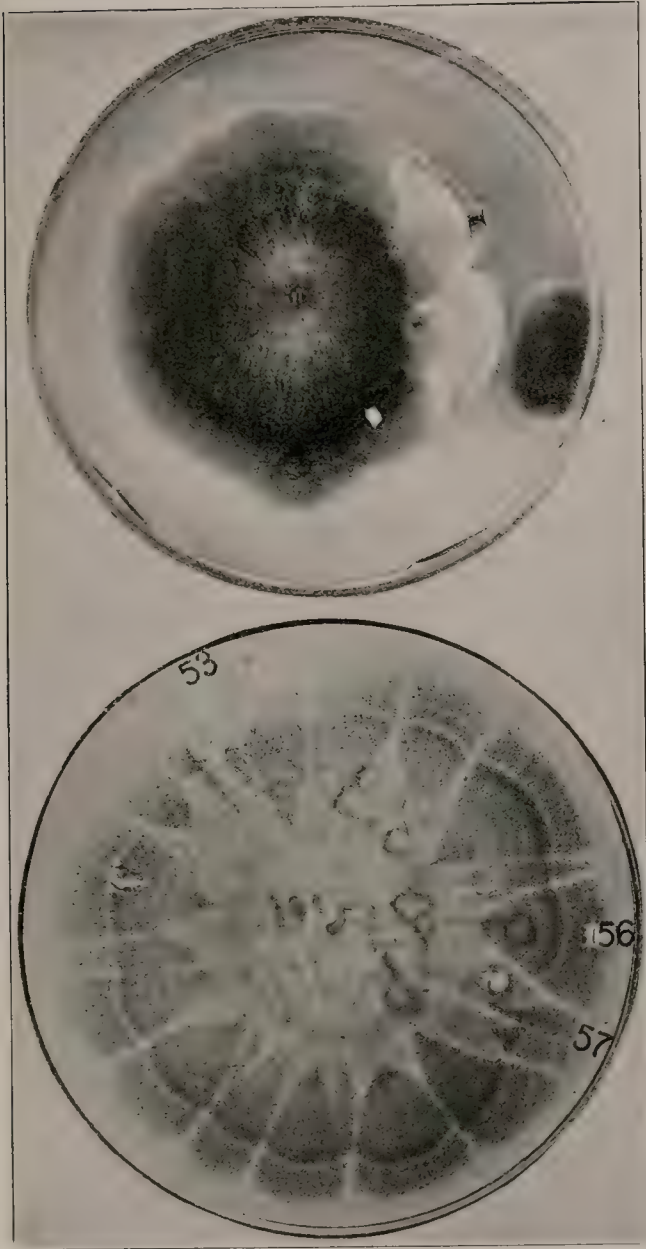


PLATE XXXI

M26-1 as it appeared on two separate plates.

PLATE XXXI



PLATE XXXII

M125. Pale colonies, showing dark sectors which were apparently reversions to the original form.

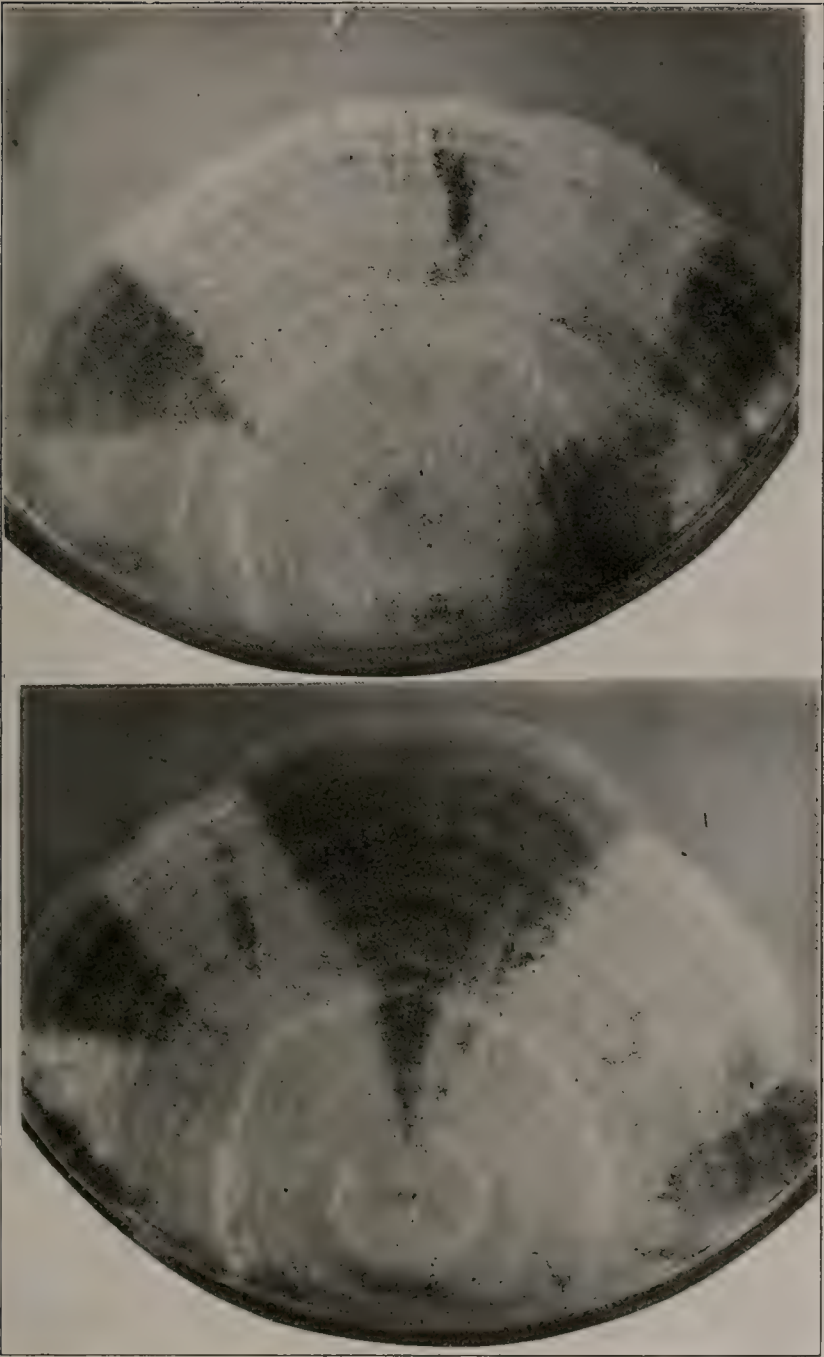


PLATE XXXIII

Showing method of using rag doll in inoculations (*a*, *b*, *c*) and also (*d*) vial and paper cylinder for soil inoculation: *a*, the rag doll unrolled in sterile Petri-dish, and aseptic wheat seedlings in place, ready for inoculation; *b*, doll in place in tube and seedlings growing; *c*, showing development of root hairs in condition for inoculation below the doll; *d*, as stated above.

PLATE XXXIII

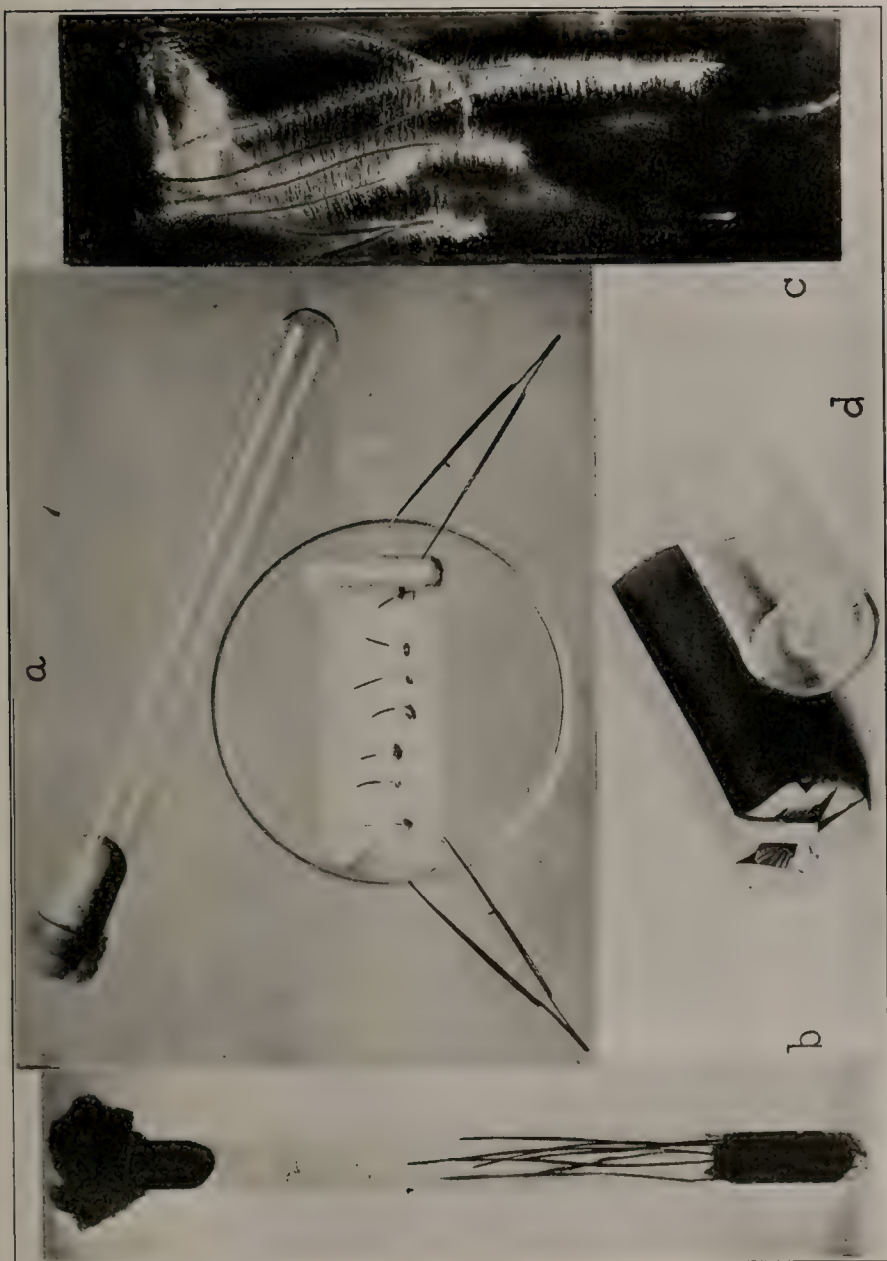
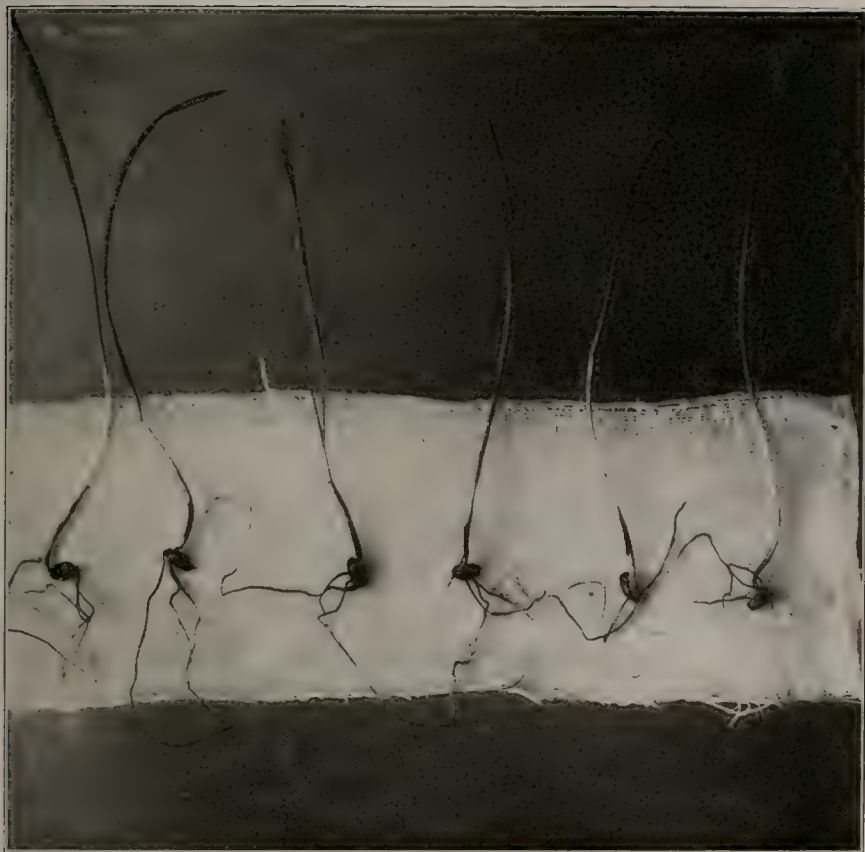


PLATE XXXIV



Rag doll opened for examination 6 days after inoculation. All the seedlings show beginnings of foot-rot.

STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION
NATURAL HISTORY SURVEY DIVISION
STEPHEN A. FORBES, Chief

Vol. XIV.

BULLETIN

Article VI.

The Numbers and Local Distribution in
Summer of Illinois Land Birds
of the Open Country

BY

STEPHEN A. FORBES

and

ALFRED O. GROSS



PRINTED BY AUTHORITY OF THE STATE OF ILLINOIS

URBANA, ILLINOIS

April, 1922

STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION
W. H. H. MILLER, *Director*

BOARD OF
NATURAL RESOURCES AND CONSERVATION
W. H. H. MILLER, *Chairman*

WILLIAM TRELEASE, *Biology*
JOHN M. COULTER, *Forestry*
ROLLIN D. SALISBURY, *Geology*
WILLIAM A. NOYES, *Chemistry*

JOHN W. ALVORD, *Engineering*
KENDRIC C. BABCOCK, *Representing the*
President of the University of Illi-
nois

THE NATURAL HISTORY SURVEY DIVISION
STEPHEN A. FORBES, *Chief*



SCHNEPP & BARNES, PRINTERS
SPRINGFIELD, ILL.
1922

62354—1200

ARTICLE VI.—*The Numbers and Local Distribution in Summer of Illinois Land Birds of the Open Country.* BY STEPHEN A. FORBES AND ALFRED O. GROSS.

In 1913 the senior author of this paper published the product of a statistical study of the midsummer birds of Illinois,* based on a part of the data collected by the junior author in the summer of 1907 by methods already repeatedly described, and of that paper the present one is to be taken as a revision and continuation. The data of 1907 were derived from 7693.5 acres (almost all in farms) traversed in 428 miles of travel on foot, of which 41 per cent. was in northern, 26 per cent. in central, and 33 per cent. in southern Illinois. The fact that only tentative general conclusions could be drawn from a single year's study was clearly recognized in the beginning, as is shown by the following statement in a first paper on the general subject†:

"The circumstance that the data of this paper are summarized in numerical tables must not be permitted to obscure the fact that they merely present a fixed picture of a fleeting condition; that they are to be taken only as numerical generalizations of the observations here recorded, and do not, in themselves, warrant much by way of inference beyond their immediate contents * * *. Definite conclusions of permanent value concerning the numbers and significance of the bird life of the state evidently can not be drawn until many such pictures as these have been assembled, compared, and adjusted in their right relations."

It was hence particularly desirable that additional data should be collected during at least a part of a second year in order that it could be seen to what extent those of the first year might have a somewhat general application, and in order also that by a combination of the two sets of data a broader basis might be had for generalizations of more stable value; and this was done by a substantial repetition, during the three summer months of 1909, of the summer program of 1907.

There was a further special reason for repeating our first midsummer observations. The length of the State of Illinois from north to south brings its extremes into materially different climates, and necessitates its division, for comparative purposes, into northern, central, and southern sections; but these differ also in the time of onset of the annual seasons and the length of the period over which each season

* The Midsummer Bird Life of Illinois. By Stephen A. Forbes. Bul. Ill. State Lab. Nat. Hist., Vol. IX, p. 373-404.

† An Ornithological Cross-section of Illinois in Autumn. By Stephen A. Forbes. Bul. Ill. State Lab. Nat. Hist., Vol. VII, p. 332-333.

prevails.† The observations of the summer of 1907 were made in the early part of the season (June 4 to July 1) for southern Illinois, at the middle of it (July 9 to 24) for central Illinois, and during the latter part of it (July 29 to August 3) for the northern part of the state. By this program observations of the early summer in southern Illinois were brought into comparison with those of late summer in the northern section, and it was hence not possible to distinguish clearly in all cases between regional and seasonal differences in the bird life of these sections. To minimize differences due to season merely, in order that those due to climate and other sectional factors might stand out more clearly, the field program of the second summer (that of 1909) was so arranged that observations were made in early, middle, and late summer in each section of the state, those for southern Illinois June 8 to 17, July 13 to 21, and August 17 to 26; those for central Illinois June 22 to 29, July 23 to 31, and August 28 to September 4; and those for northern Illinois June 30 to July 8, August 4 to 13, and September 6 to 15. Furthermore, in order to give greater variety and validity to the whole body of observations of the two years taken together, those of the second year were given different location and range from those of the first. In 1907 continuous trips had been made between widely separated points, but in 1909 certain places were chosen as centers of characteristic districts, and from these relatively short trips were made in various directions.

In this second summer the total distance traveled by the observers was 654 miles, and the area covered by their observations was 11,624 acres—an increase of 51 per cent. over that of the earlier year. Forty-one per cent. of the total area of 1909 was in northern, 33 per cent. in central, and 26 per cent. in southern Illinois. The area covered in the two summers was 19,317.6 acres.

Notwithstanding the effort made to give a different range to the later observations, the general features of the country traversed in the two years were very similar, as is shown by the following table of the

CROP AREAS, PER CENT., SUMMERS OF 1907 AND 1909

Crops	Northern Illinois		Central Illinois		Southern Illinois	
	1907	1909	1907	1909	1907	1909
Corn	31	31	46	43	23	28
Small grain*	27	24	26	28	21	35
Forage crops	37	38	27	25	44	33
Miscellaneous	5	7	1	4	12	14

* Including stubble and plowed ground.

† The significance of the north and south extension of the state is further illustrated by the fact that three faunal zones are represented in its area, the lower austral in southern Illinois, the upper austral in central, and the transitional in the extreme northern part of the state.

percentage of the whole area of observation for each year which was in each of the principal farm crops.

For the northern and central parts of the state the agreement between the two years is remarkably close, but there are noticeable differences between them in southern Illinois, due to the larger area in small grain in 1909, an increase evidently made at the expense of the forage crops. The comparison just made assures us, however, that any differences of importance noted in the bird life of the two years in the different sections were not attributable to differences in agricultural conditions.

The most striking general difference was in the seeming *greater abundance* of birds in 1909, in all three sections of the state. It is best shown in the following table of the numbers of birds recognized and counted and the number per square mile in each section of the state and in the state as a whole.

NUMBERS OF BIRDS SEEN AND NUMBERS PER SQUARE MILE,
SUMMERS OF 1907 AND 1909

Section	Number of birds			Numbers per square mile		
	1907	1909	Both years	1907	1909	Both years
Southern	2667	3973	6640	682	841	769
Central	2047	6368	8415	650	1071	925
Northern	3026	7647	10673	610	1021	857
State	7740	17988	25728	644	990	852

From this it appears that the number seen per square mile averaged 54 per cent. larger for the whole state in 1909 than in 1907, and that the increase was especially striking in central Illinois, where it amounted to 65 per cent. That this was a general and not a local phenomenon in Illinois is shown by our tables of the number of birds per square mile of different crops in different sections of the state. From these it appears that the numbers per mile recorded in 1909 exceeded those of 1907 in fields of corn, oats, stubble, plowed ground, pasture, orchards, woodlands, and yards and gardens and fell short of the 1907 numbers in wheat, meadow, shrubbery, and waste and fallow, and that the total of the areas of the first of these lists was 14,872 acres and that of the second list 4333 acres, the birds being more abundant in 1909 than in 1907 on tracts aggregating nearly three and a half times as great an area as those in which the 1909 numbers were smaller than those of 1907.

The possible causes of so sudden and so great an apparent increase in the bird population of the state are too numerous and too wide-spread to come within the range of our inquiries; but the fact itself is important, especially as showing the need of prolonged investigation as a basis for

generalization in this field. Among the minor illustrations of this fact is the disagreement of the second year's data with a conclusion reached in an earlier paper* already cited, to the effect that the total number of our summer birds increases from north to south in Illinois. This seemed to be true by our data of 1907, but it was not at all so by those of 1909; and when the averages for both years are brought together, as in the preceding table, we see that the numbers per square mile are larger for southern Illinois than for northern but are largest of all for the central part of the state.

NUMBERS OF GREGARIOUS AND SOLITARY SPECIES, RESPECTIVELY

In a search for possible causes of the marked increase of numbers throughout the state noted in 1909, we have tabulated separately the data for our nine principal gregarious species, namely, the English sparrow, quail, mourning dove, crow, bobolink, cowbird, red-winged blackbird, crow-blackbird, and goldfinch, and have brought these into comparison with the data for the solitary species remaining, with the result that the increase in numbers in 1909 is found almost wholly in the gregarious group. While the numbers of the solitary species per square mile in 1909 average for the whole summer and the whole state 6 per cent. larger than in 1907, those for the gregarious species are 2.39 times as large.

This fact raises the question whether the indicated increase in numbers was real, or only apparent and due to the insufficiency of our data. The unit of observation of the solitary species is the single bird, while that of the gregarious species is often a group of companions varying from a small flock to many hundreds. A record of a thousand solitary birds thus represents a larger number of separate observations than one of the same number of gregarious birds, and the averages in the latter case are less likely to be valid than in the former.

The social birds are not always gregarious, however, most of them scattering during their nesting season and often when in search of food, assembling only at the time of the spring migration and in late summer and fall after their young have become independent. That the actual number of gregarious birds to a single observation is much smaller than might be supposed, is shown by one of our tables which enables us to make a comparison between seven gregarious species and seventeen of the most abundant solitary species with respect to the average numbers recorded for each field or other unit of area covered by the summer survey of 1907. By this table it appears that the gregarious birds ranged in number per record from 2.4 for the mourning dove to 9.1 for the crow-blackbird, with an average of 6 per record for the seven species; while the corresponding numbers for the seventeen solitary species ranged from 1.3 for the brown thrasher and the red-headed woodpecker

* The Midsummer Bird Life of Illinois, *loc. cit.*, p. 375-376.

to 3.5 for the robin, with a general average of 2.1 per record for the group. In other words, the number of gregarious birds to the observation was less than three times the number of the more abundant solitary species; but it follows from even this fact that for equally valid averages and generalizations the number of observations of gregarious birds should be about three times as great as for the solitary species.

A further examination of the details of our tabulated data concerning the most abundant gregarious birds leads us to believe that, with three exceptions, the variations in numbers at different times and in the several sections of the state are not unusual as compared with the range of corresponding variations in the numbers of the solitary species, and

ACREAGE OF SURVEY
AND NUMBERS OF MOST ABUNDANT GREGARIOUS BIRDS,
SUMMERS OF 1907 AND 1909

	1907	1909	Both years
Acreage of Survey:			
Southern Illinois	2504.08	3023.11	5527.19
Central Illinois	2017.09	3806.80	5823.88
Northern Illinois	3172.39	4794.14	7966.53
Totals	7693.56	11624.05	19317.60
Numbers of gregarious birds recorded:			
English sparrow	1414	4239	5653
Quail	91	224	315
Mourning dove	461	670	1131
Crow	89	287	376
Bobolink	119	631	750
Cowbird	102	1845	1947
Red-winged blackbird	347	573	920
Bronzed grackle (crow-blackbird)	900	2455	3355
Goldfinch	158	231	389
Totals	3681	11155	14836
Birds per square mile	306	614	492
Numbers of above birds with three doubtful species omitted	2560	6224	8784
Birds per square mile	213	343	291

that with these exceptional cases eliminated our recorded numbers of gregarious birds per square mile may be accepted as fairly representative of the actual facts for these two years. The doubtful species are the cowbird, the crow-blackbird, and the bobolink, to be dropped from the computation for the following reasons:

The crow-blackbirds recorded, numbered 900 in 1907 and 2455 in 1909, and we omit the species from this comparison because the excess was found mainly in September in two situations in a single section of the state—that is, in yards and in corn fields in northern Illinois. The cowbird is omitted for a like reason, its numbers being 93 in 1907 and 1845 in 1909, of which 1302 were in large flocks seen in September in yards and corn fields, in northern Illinois.

The bobolink is dropped merely because of the restriction of its summer range to the northern part of the state, where the numbers seen were 743 for the two years together as compared with seven (doubtless caught in migration) in the two other sections of the state.

With these three species omitted, we have remaining 235 gregarious birds to the square mile in 1907 and 343 to the mile in 1909, an increase in the latter year of 46 per cent., which we are disposed to take as actual, but of the causes of which we can offer at present no explanation.

MOST ABUNDANT SPECIES, BOTH YEARS

The list of birds recognized and counted in the summer months of 1907 contained 85 species names and the corresponding list for 1909 contained 117 names. Most of the species were seen in both years, the entire list for both numbering only 125; or if we include the species noted in an orchard survey of 1908, the total is 133. Many of the species of these lists were represented by relatively insignificant numbers, 21 of the species seen in 1907 and 19 of those seen in 1909 making up 85 per cent. of the total number of birds seen in those years. The 21 most abundant species of 1907 aggregated 550 to the square mile, and the remaining 68 species only 95 to the mile; and the 19 most abundant species of 1909 aggregated 842 to the mile, and the remaining 88 species only 148.

The 19 most abundant birds of 1909, making up 85 per cent. of all the birds seen in that year, are all on the corresponding list for 1907, the latter differing only by the addition of two names, grasshopper sparrow and upland plover, not on the 1907 list. When we compare the numbers, and especially the ratios, of the different species (the base of the percentages being the total numbers of birds seen), we find a fairly good agreement for the two years, with a few somewhat striking differences, largely of the more gregarious species, as shown by the following table.

The most marked discrepancies between the two years are in the percentages of the cowbird, bobolink, and dickcissel, those of the cowbird in one year being about nine times those in the other, and those of

THE MOST ABUNDANT BIRDS, SUMMERS OF 1907 AND 1909

Species	Number seen			Per cent. of all birds seen			Ranking as to numbers		
	1907	1909	1907 and 1909	1907	1909	1907 and 1909	1907	1909	1907 and 1909
English sparrow	1414	4239	5653	18.2	23.6	22.1	1	1	1
Meadowlark	1025	1434	2459	13.2	8.0	9.6	2	4	3
Bronzed grackle*	900	2455	3355	11.6	13.6	13.0	3	2	2
Mourning dove	461	670	1131	6.0	3.8	4.4	4	5	5
Dickcissel	393	353	746	5.1	2.0	2.9	5	11	8
Red-winged black- bird	347	573	920	4.5	3.2	3.6	6	7	6
Prairie horned lark	296	414	710	3.8	2.3	2.8	7	9	9
Flicker	197	419	616	2.5	2.3	2.4	8	8	10
Robin	194	417	611	2.5	2.3	2.4	9	10	11
Field sparrow	186	294	480	2.4	1.7	1.9	10	12	12
Goldfinch	158	231	389	2.0	1.3	1.5	11	15	13
Kingbird	126	184	310	1.6	1.1	1.2	12	18	17
Bobolink	119	631	750	1.5	3.6	2.9	13	6	7
Grasshopper spar- row	110	0	110	1.4	0.0	0.4	14	..	20
Brown thrasher	104	204	308	1.3	1.1	1.2	15	17	18
Red-headed wood- pecker	99	259	358	1.3	1.4	1.4	16	14	15
Barn swallow	96	159	255	1.2	0.9	1.0	17	10	19
Cowbird	102	1845	1947	1.3	10.3	7.6	18	3	4
Quail	91	224	315	1.2	1.2	1.2	19	16	16
Upland plover	89	0	89	1.1	0.0	0.3	20	..	21
Crow	89	287	376	1.1	1.6	1.5	21	13	14
Totals	6596	15,292	21,888	85.3	85.0	85.1			
Per square mlle	549	842	725						

the other two species two and a half times. By combining the numbers of each species for both years, we get the most authentic record obtainable from our data, and by this means we see that the eleven principal species of the summer birds of the whole state, were the English sparrow, crow-blackbird, meadowlark, cowbird, mourning dove, red-winged blackbird, bobolink, dickcissel, prairie horned lark, flicker, and robin, abundant in the order named. These eleven species taken together aggregated 74 per cent. of all the birds counted in the summer months of the two

* Commonly known in Illinois as the crow-blackbird, or common blackbird.

years and averaged as a group 624 to the square mile, while the numbers of the 114 remaining species amounted to 228 to the mile.

THE MOST ABUNDANT BIRDS BY SECTIONS OF THE STATE

Eighty-five species and one variety of birds were recognized and counted in southern Illinois in the summers of 1907 and 1909 and twenty-two of these were so abundant as to comprise 83 per cent. of the total number of birds, leaving but 17 per cent. for the other sixty-four species. Otherwise stated, twenty-two species averaged 250 birds each while the remaining 64 species averaged only eighteen each. The more common 25 per cent. of the different kinds of birds were about fourteen times as numerous per species as the less common 75 per cent. The commoner group of 22 species averaged 638 birds to the square mile, and the less common group 130 to the mile, the former with one bird to the acre and the latter with about five acres to the bird.

NUMBERS OF PRINCIPAL SUMMER BIRDS OF SOUTHERN ILLINOIS IN 1907 AND 1909 (22 SPECIES)

(83 PER CENT. OF ALL THE BIRDS SEEN)

Meadowlark	1293
English sparrow	795
Mourning dove	518
Field sparrow	322
Dickcissel	314
Red-winged blackbird.....	278
Bronzed grackle	274
Quail	241
Robin	165
Brown thrasher	137
Kingbird	119
Cowbird	116
Mockingbird	112
Blue jay	111
Red-headed woodpecker	105
Orchard oriole	103
Bluebird	96
Grasshopper sparrow	93
Killdeer	87
Flicker	82
Maryland yellow-throat	78
Indigo bunting	75
Total	5514

When we come, however, to compare southern with central Illinois, we find a striking difference in respect to the number of dominant species. The southern part of the state is much more broken and diversified than the central—contains, that is, a greater variety of situations, each with its more or less definite group of characteristic or dominant

birds. The number of these dominant species is thus much larger and the number of birds to the species is correspondingly smaller than in the comparatively level, uniform territory of central Illinois. Although the areas covered by the bird survey were approximately equal in these two sections of the state,* and the number of birds seen was nearly 27 per cent. greater in central Illinois than in southern, the number of species was 20 per cent. smaller and the dominant species were much fewer—85 per cent. of all the birds belonging to thirteen species instead of twenty-two, and these averaging 553 to the species instead of the 250 of southern Illinois.

The average frequency of all birds in the central section was 925 per square mile, and 791 of these (86 per cent.) belonged to the thirteen more abundant species; while the birds of the remaining fifty-nine species, if equally distributed, would each have had about ten acres to itself.

NUMBERS OF PRINCIPAL BIRDS
OF CENTRAL ILLINOIS,
SUMMERS OF 1907 AND 1909
(13 SPECIES)

(85.5 PER CENT. OF ALL THE BIRDS SEEN)

English sparrow	1865
Cowbird	1744
Bronzed grackle	1111
Meadowlark	630
Mourning dove	407
Dickcissel	283
Red-winged blackbird	225
Prairie horned lark	204
Flicker	184
Robin	170
Brown thrasher	133
Red-headed woodpecker	125
Crow	115
Total	7196

Northern Illinois has a somewhat more uneven and diversified surface than the central section of the state, but much less so than the southern, and consistently with these facts we find that 15 of its species made up 84.4 per cent. of its bird population in 1907 and 1909, 79 species contributing but 15.16 per cent., the former group averaging 698 birds of each species and 723 to the square mile, and the latter group but 21 to the species and 131 to the square mile.

Illustration from May-beetles.—The relation shown in the complexity of an environment and the number of dominant species of birds, which it contains is paralleled in a convincing way by data derived from extensive collections of Illinois May-beetles made for the senior

* 5527.19 acres in southern Illinois and 5823.88 in central.

NUMBERS OF PRINCIPAL BIRDS
OF NORTHERN ILLINOIS,
SUMMERS OF 1907 AND 1909
(15 SPECIES)

(84.4 PER CENT. OF ALL THE BIRDS SEEN)

English sparrow	2993
Bronzed grackle	1970
Bobolink	743
Meadowlark	536
Prairie horned lark	451
Red-winged blackbird	417
Flicker	350
Robin	276
American goldfinch	257
Mourning dove	206
Crow	197
Barn swallow	160
Vesper sparrow	151
Grasshopper sparrow	151
Dickeissel	149
Total	9007

author in 1907 to 1912 when he was state entomologist of Illinois. In an article on the subject published in the Twenty-ninth Report of that office* is a tabulation of the distribution by sections of the state of 114,493 specimens of thirty-four species of May-beetles (Phyllophaga), from which it appears that, with these insects also, the number of dominant species is greatest in southern Illinois, where 8 out of 30 species make up 85 per cent. of the total number taken; smallest in central Illinois, where 3 of 28 species made up 81.7 per cent., and 4 species made 91 per cent.; and intermediate to these in the northern part of the state, where 5 of 21 species made up 85 per cent. of the whole number taken. The average number of each dominant species differs, of course, in the same direction. In southern Illinois the eight most abundant May-beetles were represented by an average number of 2959 specimens each and the remaining 22 by only 103 each. In central Illinois the corresponding numbers were 17,952 each for the four commonest species and 291 each for the 24 others, and in northern Illinois they were 2619 each for five of the species and 112 each for the remaining 21.

THE MOST ABUNDANT SPECIES OF THE WHOLE STATE

By uniting into one the three preceding lists and filling in the numbers of each species in all the columns for the sections of the state, we make up the following table, in which it is easy to distinguish the eleven principal species for the whole state. This comprises all whose numbers are larger than 500, and the twenty-nine species of this table

* A General Survey of the May-beetles (Phyllophaga) of Illinois, by S. A. Forbes, State Entomologist, p. 23-70.

aggregate more than 90 per cent. of all the birds recorded during the two summers covered by this discussion.

NUMBERS OF PRINCIPAL BIRDS IDENTIFIED IN EACH SECTION,
AND IN THE WHOLE STATE*
(29 SPECIES)

A. O. U. numbers	Species	S. Ill.	C. Ill.	N. Ill.	Whole state
273	Killdeer	87	23	64	174
289	Quail	241	53	21	315
316	Mourning dove	518	407	206	1131
406	Red-headed woodpecker	105	125	128	358
412	Flicker	82	184	350	616
444	Kingbird	119	52	139	310
474b	Prairie horned lark	55	204	451	710
477	Blue jay	111	37	52	200
488	Crow	64	115	197	376
494	Bobolink	5	2	743	750
495	Cowbird	116	1744	87	1947
498	Red-winged blackbird	278	225	417	920
501	Meadowlark	1293	630	536	2459
506	Orchard oriole	103	3	6	112
511b	Bronzed grackle	274	1111	1970	3355
	English sparrow	795	1865	2993	5653
529	Goldfinch	74	58	257	389
540	Vesper sparrow	1	22	151	174
546	Grasshopper sparrow	54	93	151	298
552	Lark sparrow	93	6	7	106
563	Field sparrow	322	59	49	430
598	Indigo bunting	75	14	27	116
604	Dickcissel	314	283	149	746
613	Barn swallow	4	91	160	255
681	Maryland yellow-throat	78	19	7	104
703	Mockingbird	112	7	1	120
705	Brown thrasher	137	133	38	308
761	Robin	165	170	276	611
766	Bluebird	96	22	79	197
Numbers of dominant species		22	13	15	11

* Black-face figures show dominant species in each section.

CHANGE OF NUMBERS FROM NORTH TO SOUTH

In an earlier paper on the midsummer bird-life of Illinois, already cited, it was reported that, according to our data of 1907, the English sparrow decreased in numbers in the summer time from north to south in Illinois, but that the numbers of the native summer residents increased in that direction by something like 16 per cent. for central Illinois and

29 per cent. for southern Illinois. When, however, we bring together our data for the two seasons, as in the table on page 197, and compare sectional numbers for the different species, we find that ten species sufficiently abundant to make them available for comparison show a marked progressive increase in numbers from north to south, and that eleven species show a decrease in that direction as follows:

THE MORE ABUNDANT BIRDS WHICH SHOW A
PROGRESSIVE CHANGE IN NUMBERS IN SUMMER
FROM NORTH TO SOUTH IN ILLINOIS
(DATA OF 1907 AND 1909)

<i>Increase</i>	<i>Decrease</i>
Quail	English sparrow
Mourning dove	Red-headed woodpecker
Meadowlark	Flicker
Orchard oriole	Prairie horned lark
Lark sparrow	Crow
Field sparrow	Bobolink
Dickcissel	Bronzed grackle
Maryland yellow-throat	Vesper sparrow
Mockingbird	Grasshopper sparrow
Brown thrasher	Barn swallow
	Robin

The general summer range of two of the above species—the mockingbird and the bobolink—is so definitely limited as to make their preponderance in southern and northern Illinois respectively a matter of course. Indeed, it seems probable that in so level and uniform a state as Illinois, where there are few topographical barriers to the distribution of birds, the contrasts in numbers between the north and the south are mainly due to differences in the general range of the species, those whose centers of general distribution lie to the northward of the state diminishing in number in Illinois toward the southern boundary of their midsummer range, and the Illinois numbers of those whose distribution centers lie southward increasing in that direction.

The degree of overlapping and intermingling of northern and southern species in central Illinois will vary somewhat with the character of the season, as the different species differ in susceptibility to peculiarities of temperature, humidity, and other features of the spring and summer weather. Variations in the abundance or scarcity of the principal elements of the food of the various species may have a similar effect to limit or extend their midsummer distribution in a way to affect them variously. Those, for example, with a fixed and narrow range of food preferences will be severely checked in their migrations by a local deficiency of their favorite food, while others, with less discriminating tastes, may find the deficiency of certain food elements compensated by an unusual abundance of other food.

BIRDS AND VEGETATION AREAS

The several vegetation areas of our survey, may be arranged for convenient comparison in the order of the numbers of birds to the square mile, as in the following table.

VEGETATION AREAS AND BIRDS PER SQUARE
MILE IN EACH, THE WHOLE STATE,*
SUMMERS OF 1907 AND 1909

Vegetation	Acres	Birds
Orchards	117.69	3943
Yards and gardens	557.39	3418
Swamps	83.66	1974
Woodlands	111.96	1846
Pastures	5196.06	1068
Shrubbery	93.31	1056
Meadows	2763.02	910
Wheat, rye, and barley	822.36	827
Waste and fallow	654.17	787
Plowed ground	300.16	670
Stubble	1069.46	669
Corn	6433.63	593
Oats	2485.57	514
Miscellaneous	29.16	329

* The general state average of all birds, both summers, taken together, was 852 to the square mile.

Half of these 14 classes of area carry a bird population exceeding the average for the state as a whole, and half of them fall below that average. Of the larger areas, each comprising from 1000 to 6000 acres or more and aggregating 85 per cent. of all our census territory, pastures and meadows stand highest, with corn and oats falling much below the average. Generally speaking, the smaller areas attract the largest numbers of birds to the square mile, possibly because, as we have found to be clearly the case with orchards,* the characteristic birds of a single kind of vegetation area are scattered where the area is large, and concentrated where it is small. Of these smaller areas, orchards stand much the highest, with nearly five times the average concentration, and yards and gardens next, the birds of all these situations showing by their local numbers, a high degree of adaptation to the companionship and life of man. Swamps and open woodlands are almost the only approximately wild places on our list, and these contain about twice as many birds as the general average, but less than half

* "The Orchard Birds of an Illinois Summer", by Stephen A. Forbes and Alfred O. Gross. Bul. Ill. State Nat. Hist. Survey, Vol. XIV, p. 1-8.

as many as the areas of human neighborhood. Their total of some 200 acres is, however, rather small for any definite inference.

THE BIRD LIFE OF ILLINOIS PASTURES

On the 3796 acres of pasture whose bird population was accurately ascertained in the two summers, an average of 1068 birds to the square mile was found—1041 in northern, 1274 in central, and 937 in southern Illinois. If we separate the data for the different years, we find an average for the state of 881 to the square mile in 1907 and 1194 to the mile in 1909, the excess for the latter year being 36 per cent. in northern Illinois, 29 per cent. in central Illinois, and 30 per cent. in southern.

The 6335 birds identified in pastures belonged to ninety-six species, but 85 per cent. of these belonged to twenty-three species, leaving but 15 per cent. for the other seventy-three. There was thus no small distinctive group of pasture birds, such as were found in some other habitats, but the pasture was merely one of the preferred resorts of a rather long list of species, every one of which was, in fact, found in one or more other situations more frequently than there.

The English sparrow stood at the head of the list of pasture visitants, but the meadowlark led the native birds in each year and in each section of the state, and was found in southern Illinois pastures more than twice as common as the sparrow. The crow-blackbird, or bronzed grackle, was third in order of numbers in both years and in the whole state, but it was surpassed in the southern part of the state by the field sparrow and the mourning dove, and in central Illinois by the cowbird. Among other more prominent birds were the flicker (which was, however, only about a third as common in southern Illinois pastures as farther north), the robin, also much the least abundant in southern pastures, the prairie horned lark, much the commonest in northern Illinois, and the red-winged blackbird.

Comparing the data of the two years, we find 13 of the 23 most abundant species represented by notably larger numbers per square mile in 1909 than in 1907, two of them by fewer, and 8 by virtually equal numbers. The group of pasture birds thus gives the same indication of increased numbers in 1909 as do the combined data from all situations. Additional particulars concerning these species may be gathered from the following table.

From the known food habits of the more abundant pasture species it appears that the meadowlark and the crow-blackbird are the kinds most serviceable, under ordinary conditions, as a pasture police for the control of injurious insects. When a considerable outbreak of a destructive species occurs, many other birds attracted by unusual chances for "loot" will come to the aid of the regular force; but it is to the less conspicuous services of constant residents and frequent visitants that the farmer must look for a steady pressure upon the multiplication

PRINCIPAL PASTURE BIRDS PER SQUARE MILE,
SUMMERS OF 1907 AND 1909

Species	Southern	Central	Northern	1907	1909	Whole state, both years
Meadowlark	240	168	79	143	157	151
Bronzed grackle	46	101	72	49	88	72
Cowbird	16	162	22	11	85	55
Robin	27	72	53	35	60	50
Prairie horned lark	21	27	72	47	48	48
Flicker	19	53	63	29	59	47
Mourning dove	50	76	14	31	47	41
Red-winged blackbird	34	27	35	23	39	33
Field sparrow	57	27	8	41	19	28
Red-headed wood-pecker	18	36	27	22	29	26
Bobolink	2	1	53	8	35	24
English sparrow	102	244	191	176	178	177
Goldfinch	8	9	37	17	24	21
Barn swallow	2	45	25	17	27	23
Brown thrasher	23	26	15	14	24	20
Kingbird	21	21	17	20	19	19
Crow	8	19	27	14	19	19
Bluebird	17	11	25	14	23	19
Quail	28	11	8	14	15	15
Killdeer	6	8	19	15	10	12
Dickcissel	18	21	4	13	12	12
Blue jay	15	9	10	11	11	11
Grasshopper sparrow	9	12	10	9	10	9
Totals	787	1186	886	773	1038	932
Per cents. of all birds	84	93	86	88	87	87

of cutworms, grasshoppers, May-beetles, and other ordinary insect pests of the pasture.

THE MEADOW BIRDS

In Illinois meadows the meadowlark justified its name by an abundance virtually double that of any of the other "most abundant" birds—194 to the square mile as compared with 100 for the dickcissel and 94 for the English sparrow. In northern Illinois it was surpassed by the bobolink (201 to the square mile and 102 for the meadowlark), but the absence of the bobolink from the more southern sections reduced its meadow average for the state to 96.

Fourteen species made up 82 per cent. of all the birds identified in meadows, and more than half the whole number of birds belonged

to the four species mentioned above. Next in order came the crow-blackbird, red-winged blackbird, and grasshopper sparrow, found in nearly equal numbers per square mile, those for the seven other more abundant species ranging from 31 to the mile down to 9.

PRINCIPAL MEADOW BIRDS PER SQUARE MILE,
WHOLE STATE,
SUMMERS OF 1907 AND 1909

Species	Southern	Central	Northern	1907	1909	Whole state, both years
Upland plover	4	67	22	19	30	25
Mourning dove	36	35	22	31	27	29
Flicker	7	51	40	37	26	31
Kingbird	10	7	21	19	11	15
Prairie horned lark	1	5	41	23	19	21
Bobolink	0	0	201	12	166	96
Red-winged blackbird	80	32	18	50	34	41
Meadowlark	319	204	102	204	185	194
Bronzed grackle	18	85	55	81	21	49
English sparrow	54	85	126	112	79	94
Grasshopper sparrow	19	64	48	56	29	41
Dickcissel	155	179	29	122	81	100
Barn swallow	0	10	16	12	7	0
Robin	7	13	17	17	10	13
Totals	710	837	758	795	725	749
Per cents. of all birds	78.7	83.9	87.1	86.8	81.6	83.4

Compared with pastures, meadows were distinguished by the somewhat greater prominence of the meadowlark (194 to 151), the exclusive habitation of the bobolink (96 to 0), the much greater prevalence of the dickcissel* (100 to 12) and the grasshopper sparrow (41 to 10), and the greater abundance of the red-winged blackbird (41 to 33). As against this list of distinctive meadow birds there is a much longer list of those to which the meadow was less attractive than the pasture. The principal of these are the English sparrow (94 to the square mile in meadow and 177 in pasture), the crow-blackbird (49 to 72), the robin (13 to 50), the prairie horned lark (21 to 48), the flicker (13 to 47), and the mourning dove (29 to 41). With the possible exception of the last, these differences are fairly consistent with the known food and habits of the several species. This obvious preference of the species mentioned for pastures over meadows is reflected in the average for the whole state of the meadow and pasture birds respectively (meadows, 910, and pastures, 1085, to the square mile).

BIRDS IN SMALL GRAIN AND IN STUBBLE

Wheat and oats, judging by our data, offer very similar inducements (or lack of special inducements) to birds, but with one notable exception, that of the mourning dove, of which ten times as many to the square mile were found in fields of wheat as in oats (141 to 14, respectively).

Differences seen in the numbers of the gregarious and erratic cowbirds and grackles seem to have little significance, and may probably be attributed mainly to the mere chances of unequal distribution, but with these species eliminated, the numbers of birds in wheat exceed those in oats by about 34 per cent.

NUMBERS PER SQUARE MILE OF PRINCIPAL BIRDS
IN SMALL GRAIN AND STUBBLE, WHOLE STATE,
SUMMERS OF 1907 AND 1909
(Wheat, rye, and barley, 822 acres; oats, 2486;
stubble, 1069.)

Species	Wheat*	Oats	Stubble
Quail	14	4	9
Mourning dove	141	14	40
Prairie horned lark	24	5	11
Crow	21	12	11
Bobolink	4	16	23
Cowbird	121	11	1
Red-winged blackbird	26	21	1
Meadowlark	47	50	89
Bronzed grackle	156	92	4
English sparrow	147	163	159
Goldfinch	8	10	10
Dickcissel	27	28	1
Cliff swallow	2	3	12
Robin	3	4	8
All birds	827	514	669

* Includes rye and barley.

Fields of small grain would seem to undergo so great a change as bird resorts as the grain is cut and shocked, that we might well have anticipated a marked contrast in the species and numbers found in them after harvest, but our table does not confirm this expectation, the differences between stubble fields and those of uncut grain being chiefly in the gregarious cowbirds and blackbirds, and otherwise not noticeably greater than those between fields of oats and wheat.

As a further test of this conclusion, we have tabulated separately the numbers of all species found in fields of small grain, before harvest and after the grain had been cut and shocked, but we find few consistent

or significant differences, variations in numbers in the contrasted situations being generally erratic and in different directions at different times.

A comparison of the columns of our table for the two years gives us, in fact, an impression that the grain fields are resorted to by most birds for occasional and temporary reasons, such as the superabundance of easily accessible and especially desirable food in the shocked wheat, or a scarcity of the ordinary food of the species elsewhere. The marked preference of the mourning dove for harvested wheat over any other of the situations of our table, and the unusual abundance of meadow-larks in 1909 in fields of harvested oats are probably to be thus accounted for; but the apparent preference of the dickcissel for standing grain is not so easily understood. Its uniform averages of 42 to the square mile in this situation, of only 6 or 7 in fields of shocked grain, and virtually none in naked stubble fields mean, on the face of the figures, that it finds in the growing grain important advantages which largely disappear when the grain is cut; but in view of the habits of the species, it seems to us more likely that the difference is due to the mere advancement of the season. The nesting period of the dickcissel is practically over by the time the grain is all harvested, and by the first week in August most of the birds have assembled in secluded roosts for their postjuvenal and postnuptial molts, soon after which they leave for the South. In fact, less than 10 per cent. of our dickcissels were seen after July 31 in fields of grain, either cut or uncut, and their relative scarcity in shocked wheat or oats is very likely due to their gradual withdrawal from the open country.

ACREAGE SURVEYED OF WHEAT AND OATS, UNCUT
AND CUT,
WHOLE STATE, MIDSUMMERS OF 1907 AND 1909

Crops	1907		1909	
	Uncut	Cut	Uncut	Cut
	Acres		Acres	
Wheat	134.52	151.14	201.15	123.90
Oats	531.41	601.07	454.28	669.13

ALL BIRDS, PRINCIPAL SPECIES, AND NATIVE BIRDS
IN WHEAT AND OATS, CUT AND UNCUT,
MIDSUMMERS OF 1907 AND 1909

Birds	1907							
	Wheat				Oats			
	Uncut		Cut		Uncut		Cut	
	Num- bers	To sq. mi.	Num- bers	To sq. mi.	Num- bers	To sq. mi.	Num- bers	To sq. mi.
English sparrow	77	371	9	38	55	66	231	245
Mourning dove	20	95	57	241	13	16	6	6
Meadowlark	12	57	12	51	32	39	57	61
Prairie horned lark	0	0	8	34	0	0	14	15
Dickcissel	9	43	3	13	49	59	6	6
All birds	153	728	291	1228	385	469	422	445
Native birds	76	362	282	1194	330	397	191	203
Birds	1909							
	Wheat				Oats			
	Uncut		Cut		Uncut		Cut	
	Num- bers	To sq. mi.	Num- bers	To sq. mi.	Num- bers	To sq. mi.	Num- bers	To sq. mi.
English sparrow	25	80	15	77	611	861	417	379
Mourning dove	8	25	29	150	9	13	16	15
Meadowlark	12	38	0	0	23	32	75	72
Prairie horned lark	23*	74	0	0	8	4	1	1
Dickcissel	10	32	1	5	29	41	6	6
All birds	133	423	128	635	813	1145	842	805
Native birds	108	344	113	584	202	285	425	426

* Twenty in one flock.

THE BIRDS OF THE CORN FIELD

With the exception of occasional raids made on fields of corn by flocks of crow-blackbirds and cowbirds in fall to feed on grain torn from the tips of the ears, there is little in our data to indicate that our Illinois birds find any special lure or attraction in corn fields. It is true that the English sparrow was found there in numbers averaging 130 to the square mile, but this was less by 57 than the average of the sparrow for the whole state. The blackbird, on the other hand, was more abundant in corn fields than its general average (138 and 111 to the

square mile respectively), as was also the cowbird (88 in corn fields and 64 in the state at large). None of the eleven remaining "more abundant" species necessary to bring the total up to 82.5 per cent. of all the corn field birds, was present in greater number than 29 to the square mile, the ratio of the mourning dove. The heterogeneous composition of this list of fourteen species and the moderate average numbers of each in corn fields suggests, indeed, that their presence there was "accidental" rather than purposive, and we find no evidence in our records, with the two exceptions mentioned, that there is any group of corn field birds, properly so-called. In other words, we can not say that the corn plant either profits or suffers from the visits of birds to the fields in which it is growing (again excepting, of course, the cowbird and the crow-blackbird) to any extent which we have been able to discover.

PRINCIPAL BIRDS PER SQUARE MILE OF CORN,
SUMMERS OF 1907 AND 1909

Species	Southern	Central	Northern	1907	1909	Both years
Quail	24	4	5	2	9	6
Mourning dove	50	32	14	26	32	29
Red-headed woodpecker	10	6	3	4	7	6
Flicker	5	9	14	7	12	10
Prairie horned lark	6	29	16	20	19	19
Crow	3	9	14	4	13	10
Cowbird	15	213	2	6	141	88
Red-winged blackbird	14	7	30	9	23	18
Meadowlark	25	7	2	10	9	9
Bronzed grackle	32	133	206	60	188	138
English sparrow	49	120	189	50	181	130
Goldfinch	4	5	19	12	9	10
Vesper sparrow	1	3	18	5	10	8
Brown thrasher	9	9	2	7	6	6

BIRDS ON PLOWED GROUND

Ground plowed for planting but not yet planted can scarcely be said to resemble any natural habitat, or be expected to serve as a place of assemblage for any definite group of birds, and our data, derived from three hundred acres of plowed fields, chiefly in southern Illinois, are in accord with this supposition. A record of 314 birds occurring on this area, equivalent to the very respectable average of 670 to the square mile, is attributable mainly to the prairie horned lark, which has an unexplained but well-known preference for bare earth as a resting place. On plowed ground it was usually feeding busily on tiny weed seeds lodged in the soil, as shown by its actions and by the contents of crops examined. It was more than twice as abundant in plowed fields (162 to the square

mile) as any other species, the next in order being the mourning dove (77) and cowbird (49). These and four other species—the killdeer (58), robin and upland plover (34 each), and English sparrow (30)—together made up 86 per cent. of all the birds recognized on plowed ground. The occurrence here of two species of shore birds in some numbers (22 examples of the killdeer and 14 of the upland plover) was probably due to their search for earthworms and insect larvae in the soft earth.

THE BIRDS OF THE SWAMPS

Open swampy lands are so scarce in Illinois that in 1070 miles of travel made in the summers of 1907 and 1909, only 4.6 miles were over swamps. In the area of 83.66 acres thus covered, 258 birds, belonging to thirty species, were identified, an average of 1974 birds to the square mile—about two and a quarter times the general average for the whole state. Two thirds of the swamp area was in northern Illinois, and there more than three fourths of the swamp birds were found. All of our thirty species were represented in this northern list, while on the nineteen acres of southern Illinois swamp there were but five species (the red-winged blackbird, crow-blackbird, meadowlark, dickcissel, and Maryland yellow-throat); and in $2\frac{3}{4}$ acres in central Illinois there was but one—the red-winged blackbird. The six species of the following table made up 82.6 per cent. of all the birds identified in swamps.

PRINCIPAL BIRDS OF ILLINOIS SWAMPS, SUMMERS OF 1907 AND 1909 NUMBERS PER SQUARE MILE	
Red-winged blackbird	1125
Bronzed grackle	207
Bobolink	130
Quail	76
Green heron	46
Long-billed marsh wren	46

BIRDS OF THE OPEN WOODS

Our data concerning the woodland birds are rather meager, mainly because it was impossible to use our method of identification and enumeration in any except open woodlands of comparatively small trees, and the one hundred and twelve acres accurately covered consequently made too small and too special an area to be fully representative. Furthermore, the southern Illinois forest area surveyed was more than twice as large as that of all the rest of the state, and hence the forest birds of the southern section predominate strongly in our lists for the state as a whole.

About half of the fifty species recorded from woods were distinctively forest birds, rarely if ever seen in the open fields, and especially adapted by habit, preference, and sometimes by structural endowment

also, to life among trees. Nothing of the sort can be said of the birds of the pasture or the stubble field or of other distinguishable vegetation areas of the open country.

The forest is a more complex environment than the meadow or the grain field, and its bird society is less dominated by a few conspicuous species. Thirty-one of the fifty species of our list were, in fact, necessary to bring our total of the more abundant kinds up to 85 per cent. of the whole number of birds; and the most abundant of these, the blue jay and the field sparrow, averaged only 194 and 131 to the square mile respectively. These were followed by the flicker, with 97 to the square mile, the robin, with 86, the brown thrasher and crested flycatcher, 69 each, and these, in order of numbers, by the wood pewee, crow, and mourning dove, with other species in ratios gradually decreasing to 17 to the square mile. The aggressive and presuming English sparrow, usually at the top of our lists, was in

PRINCIPAL WOODLAND BIRDS (85 PER
CENT. LIST)

IN ORDER OF NUMBERS PER SQUARE MILE,
WHOLE STATE, SUMMERS OF 1907
AND 1909

Blue jay	194
Field sparrow	131
Flicker	97
Robin	86
Crested flycatcher	68
Brown thrasher	69
Wood pewee	63
Crow	63
Mourning dove	51
Red-headed woodpecker	51
Towhee	51
Indigo bunting	51
Tufted titmouse	51
Bronzed grackle	46
English sparrow	46
Cardinal	46
Bluebird	46
Redstart	46
Goldfinch	40
Quail	34
Downy woodpecker	34
Cowbird	34
Red-winged blackbird	34
Maryland yellow-throat	34
Bewick's wren	34
Dickcissel	23
Black and white warbler	23
Wood thrush	23
Turkey vulture	17
Sparrow hawk	17
Yellow-bellied flycatcher	17

the fourteenth place of this series, with an average of only 46 to the mile, and no more abundant than the bluebird or the cardinal.

The yearly ratios of these woodland birds (2187 to the mile in 1909 and 1441 in 1907) confirm our general conclusion that birds were much the more numerous in Illinois in 1909.

BIRDS IN ORCHARDS

We have already reported on the orchard birds of a southern Illinois summer, with some reference to other parts of the state, in a paper* in which we made special use of data obtained in August and September of 1908 by a trip through a commercial orchard district of that section; and we have here to report more fully on the product of a survey of 117.69 acres of farm orchards only, of which 71 per cent. was in southern, 18 per cent. in central, and 11 per cent. in northern Illinois.

In these orchard belts, 825 birds were identified, equivalent to 4026 to the square mile. The English sparrow, however, made up more than half this number, leaving 1987 native birds to the square mile. Next to the sparrow, the more abundant species were the mourning dove (256 to the mile), quail (212), field sparrow (190), crow-blackbird (158), robin (152), brown thrasher (125), orchard oriole (120), blue jay (114), catbird (103), mockingbird (77), and flicker (76). The birds of these twelve species made up 80.4 per cent. of the aggregate number belonging to the 52 species found in these farm orchards. It will be seen from the table following that, as in other vegetation areas, the English sparrow decreased rapidly in numbers from north to south, and that both it and the native birds were much more numerous in 1909 than in 1907 (1255 native birds to the square mile in 1907 and 1746 in 1909); and this notwithstanding the fact that there were evidently no flocks of gregarious birds to confuse the record in the orchards visited.

Although the orchard is, like the open woodland, essentially a field of closely set trees with a ground cover more or less deep and dense according to its treatment, and might hence be supposed to attract the same species of birds in something like the same average number, it is really so different from a forest in the relatively small variety of foods and situations which it offers, and especially in its human environment, that the two make a widely different appeal to birds. In the comparatively simple orchard, a smaller number of species dominate, 13 out of 52 native species comprising 70 per cent. of the whole number; while in the complex forest 20 out of 49 must be taken to make up this 70 per cent. Moreover, a comparison of the corresponding species lists illustrates the wide difference of the two environments, as is shown in the table on page 211. In the first column are the numbers per square mile of birds found in farm orchards, and in the second are the numbers

* The Orchard Birds of an Illinois Summer, by Stephen A. Forbes and Alfred O. Gross. *Bul. Nat. Hist. Survey*, Vol. XIV, Art. 1, June, 1921.

PRINCIPAL BIRDS PER SQUARE MILE OF ORCHARDS,
SUMMERS OF 1907 AND 1909

	Southern	Central	Northern	1907	1909	Both years
Quail	289	31	0	15	327	212
Mourning dove	297	218	49	310	224	256
Flicker	53	187	49	74	77	76
Blue jay	114	124	98	14	172	114
Orchard oriole	165	0	0	177	86	120
Bronzed grackle	137	342	0	192	138	158
English sparrow	426	4607	8373	592	2882	2039
Field sparrow	251	62	0	163	206	190
Mockingbird	84	93	0	30	103	77
Catbird	84	124	49	14	129	103
Brown thrasher	84	249	196	118	129	125
Robin	145	187	147	148	155	152
Totals	2129	6224	8961	1847	4628	3622

in woodlands multiplied by 2.14 to compensate for difference in density of the total bird population in orchard and woodland, and thus to make the averages comparable directly.

BIRDS IN SHRUBBERY

On ninety-three acres of shrubbery, 85 per cent. of it in southern Illinois and nearly all the remainder in the northern part of the state, 154 birds belonging to 35 species were found, a number equivalent to 1056 birds to the square mile. The only especially notable item of the record is the fact that nearly a quarter of these birds were field sparrows (*Spizella pusilla*), present in numbers equivalent to 254 to the square mile. Indigo buntings and yellow-breasted chats were each about a third as numerous as the sparrows; and then came goldfinches (55 to the square mile), quail, towhees, cardinals, and Maryland yellow-throats (each 41 to the mile), blue jays, brown thrashers, and red-headed woodpeckers (each 34), bluebirds and cowbirds (27 each), and mourning doves (21), crested flycatchers, crows, meadowlarks, and robins (21 each), making in all as beautiful and interesting a group of birds as we shall find mustered in any one situation.

BIRDS OF THE FARMYARD AND GARDEN

Five hundred and fifty-seven acres of the area covered by our bird survey were made up of patches of yards and gardens of the farm premises, and on these 2977 birds were identified, a number equivalent to 3418 to the square mile. Here the English sparrow was, of

COMPARISON OF NUMBERS PER SQUARE MILE OF THE
MORE ABUNDANT BIRDS IN ORCHARDS AND IN OPEN WOODS,
SUMMERS OF 1907 AND 1909
(IN ORDER OF NUMBERS IN ORCHARDS)

Birds	Orchard	Woods (weighted)*
English sparrow	2039	98
Mourning dove	256	109
Quail	212	73
Field sparrow	190	280
Bronzed grackle	158	98
Robin	152	184
Brown thrasher	125	148
Orchard oriole	120	24
Blue jay	116	415
Catbird	103	13
Mockingbird	77	0
Flicker	76	208
Red-headed woodpecker	44	109
Chickadee	33	109
Crested fly-catcher	16	148
Indigo bunting	0	109
Wood pewee	0	135
Crow	0	135
Towhee	0	109
Cardinal	0	98
Tufted titmouse	0	109
Redstart	0	98

* To get the actual numbers per square mile found in woods, divide the numbers of this column by 2.14.

course, enormously predominant, making nearly half the total number of birds seen. The bronzed grackle was about half, and the cowbird about a third, as abundant as the sparrow. These three species together averaged 2820 to the square mile, leaving but 598 to the mile for all the other fifty-nine species seen in this situation. If to these three super-abundant birds we add seven others, of which the robin, meadowlark, flicker, mourning dove, mockingbird, and chimney swift were the most numerous, we shall include 90 per cent. of the whole number of yard and garden birds on our survey list.

The record is much distorted, however, by the occurrence in fall of large flocks of blackbirds and cowbirds during the period of their assemblage for migration; but even if we ignore these flocks, the crow-blackbird still stands next to the sparrow in numbers, although the cowbird drops quite out of the list of the more abundant species. If we omit the sparrows, we have remaining native birds equivalent to 1883 to the square mile, and if we exclude also the flocks of cowbirds and crow-blackbirds as merely aimless visitors which chanced to settle on the trees of the farmyard as a temporary convenience, we have a residue

of 1757 birds to the square mile which may be supposed to seek, or at least not obviously to avoid, the companionship of man.

WASTE AND FALLOW LANDS

Under the heading of waste and fallow lands we have brought together a heterogeneous variety of situations which have in common only the negative character of a lack of growing crops, at least for the year, and the fact that they can not be classified under any of the other vegetation areas of our grouping. These wastes and fallows seem, however, to make an appeal of their own to a more or less definite group of birds, or to many birds, perhaps, under certain conditions, for we find in them a marked inverse relation, such as we have called attention to in discussing other situations, between the acreage of this habitat in each section of the state and the birds found in it per square mile. The smaller the percentage of waste and fallow land to the general area the greater the density of its bird population, as is seen in the table following:

<i>Section</i>	<i>Acres surveyed</i>	<i>Birds per square mile</i>
Southern Illinois	479	708
Northern Illinois	147	955
Central Illinois	28	1236

It is perhaps in the central part of the state, where this special kind of surface is smallest, that we shall find among the commonest species those which may be distinguished as birds of the waste lands, and these our MS table shows to be the crow-blackbird (247 to the square mile in that section), red-winged blackbird (202), quail (202), English sparrow (157), field sparrow (112) dickcissel (112), and Maryland yellow-throat (90). In northern Illinois, it is true, the English sparrow leads the list, and the bobolink stands next, the sparrow being, in fact, most abundant northward in nearly all situations, and the bobolink confined in Illinois to that part of the state by the limitations of its general range.

If, on the other hand, we take the larger area and more numerous observations of southern Illinois as furnishing a better index to the true relations of birds and their environment, we shall find the heterogeneous character of wastes and fallows (particularly evident in that section) reflected in the absence of any strongly dominant species or group of species, and the consequent large number of species which we must take into account to include any large majority of the whole number of birds. Of the 61 species identified on 479 acres of our southern waste and fallow lands, 19 are needed to make only 72 per cent. of our total number of 804 birds from that situation.

First among these more abundant species of southern Illinois stands the meadowlark, with 182 to the square mile for the southern section and 142 for the state at large, averages to be compared with 319 for meadows in southern Illinois and 194 for those of the whole state.

Next after the meadowlark comes the red-winged blackbird, (93 to the mile), prominent by reason of its numbers in northern and central Illinois. This is followed by the English sparrow (57), much the least abundant in the southern section, the field sparrow (47), mourning dove (37), dickcissel (29), goldfinch and quail (27 each), and ten others in numbers gradually diminishing from 26 to 10 to the square mile. The species are, as a whole, derived from the prairies as represented in pastures and meadows, with only a minor invasion from forest or marsh.

**MOST ABUNDANT BIRDS IN WASTE AND FALLOW LANDS,
WHOLE STATE, SUMMERS OF 1907 AND 1909**

NUMBERS PER SQUARE MILE	
Meadowlark	142
Red-winged blackbird	93
English sparrow	57
Field sparrow	47
Mourning dove	37
Dickcissel	29
Goldfinch	27
Quail	27
Bobolink	26
Bronzed grackle	20
Kingbird	19
Brown thrasher	17
Bluebird	16
Maryland yellow-throat	15
Red-headed woodpecker	13
Blue jay	11
Crow	10
Short-billed marsh wren	10
Total	616

SUMMARY AND DISCUSSION

A compact summary of our most general averages of the numbers of our most abundant birds, as found on distinguishable vegetation areas, is given in the following table, an examination of which will enable us to point out certain conclusions not otherwise readily arrived at. The totals at the bottom of the table show the relative densities of the bird population (both with and without the English sparrow) in the thirteen recognized situations and in the total area of the survey which stands for the state as a whole.

THE MORE ABUNDANT SPECIES IN HABITATS
NUMBERS PER SQUARE MILE, WHOLE STATE, SUMMERS OF 1907 AND 1909

Species	Total number seen	State average	Meadows	Pastures	Swamps	Waste and fallow	Wheat, rye, barley	Oats	Corn	Stubble	Plowed ground	Woods	Orchards	Shrubbery	Yards and gardens
Acreage.....			2763	5196	84	654	822	2486	6434	1069	300	112	118	93	557
English sparrow.....	5653	187	94	177	23	57	147	163	130	159	30	46	2039	0	1535
Crow-blackbird.....	3355	111	49	72	207	20	56	92	138	4	28	46	158	0	761
Meadowlark.....	2459	82	194	151	31	142	47	50	9	89	21	0	44	21	55
Cowbird.....	1947	64	3	55	0	10	121	11	88	1	49	34	22	27	524
Mourning dove.....	1131	37	29	41	0	37	141	14	29	40	77	51	256	21	31
Dickcissel.....	746	25	100	12	2	29	27	28	5	1	0	23	11	20	6
Prairie horned lark.....	710	24	21	48	0	1	24	5	19	11	162	0	0	0	22
Bobolink.....	750	24	96	24	130	26	4	16	4	23	6	0	0	0	1
Flicker.....	616	20	31	47	0	7	4	6	10	2	0	97	76	0	36
Red-winged blackbird.....	920	20	41	33	1125	93	26	21	18	1	2	34	11	0	1
Robin.....	611	20	13	50	8	59	3	4	10	8	34	80	152	21	59
Field sparrow.....	430	14	10	28	0	47	9	4	5	4	13	131	190	254	4
Goldfinch.....	389	13	7	21	15	27	8	10	10	11	40	38	55	14	14
Red-headed woodpecker.....	358	12	9	26	0	13	10	5	6	5	6	51	44	34	26
Crow.....	376	12	13	19	0	10	21	12	10	11	0	63	5	21	2
Quail.....	315	11	8	15	76	27	14	4	6	9	3	34	212	41	13
Grasshopper sparrow.....	298	10	41	9	23	8	12	5	1	5	0	0	0	0	0
Brown thrasher.....	308	10	6	20	0	17	9	5	6	1	9	69	125	34	20
Kingbird.....	310	9	15	19	0	19	28	5	6	1	11	0	27	0	21
Barn swallow.....	255	8	9	23	0	8	5	8	3	5	0	0	0	0	10
Upland plover.....	218	7	25	8	0	0	28	2	2	5	34	0	0	0	6
Blue jay.....	200	7	2	11	0	11	0	1	2	1	0	194	114	34	23
Bluebird.....	197	7	4	19	0	16	1	1	2	1	15	46	11	27	7
Killdeer.....	174	6	0	12	8	1	0	0	7	0	58	0	0	0	4
Chimney swift.....	181	6	12	9	0	11	2	3	2	0	4	0	5	0	28
Vesper sparrow.....	174	6	7	5	0	4	1	3	8	1	13	0	0	0	15
Cliff swallow.....	151	6	2	9	0	0	2	3	3	13	0	0	0	0	5
Orchard oriole.....	112	4	1	1	0	4	2	0	1	0	0	11	120	14	23
Indigo bunting.....	116	4	1	3	8	9	4	2	4	1	0	51	58	82	0
Mockingbird.....	120	4	1	6	0	5	1	0	3	0	13	0	77	0	29
Lark sparrow.....	106	3	1	9	0	8	5	1	3	0	6	0	22	0	5
Song sparrow.....	93	3	3	4	38	6	1	1	3	1	0	0	5	1	5
Maryland yellow-throat.....	104	3	4	5	15	15	4	2	2	0	0	34	3	41	2
Wood pewee.....	46	2	1	3	8	1	0	0	0	2	0	63	5	0	5
Cardinal.....	54	2	1	1	0	7	0	0	1	0	0	46	38	41	0
Catbird.....	67	2	0	2	0	1	0	1	1	0	2	6	103	0	11
Green heron.....	32	1	2	2	46	1	0	0	2	0	0	6	5	0	2
Downy woodpecker.....	27	1	0	1	0	1	0	0	1	0	2	34	5	0	1
Crested flycatcher.....	25	1	0	1	0	0	0	0	0	1	0	68	16	21	1
Towhee.....	30	1	0	1	0	0	0	0	0	0	0	51	16	41	1
Yellow-breasted chat.....	20	1	0	1	0	1	0	0	0	68	0	11	0	68	1
Short-billed marsh wren.....	12	1	0	0	15	10	0	0	0	0	0	0	0	0	0
Long-billed marsh wren.....	10	1	0	0	46	4	0	0	0	0	0	0	0	0	0
Tufted titmouse.....	18	1	0	1	0	0	0	0	0	0	0	51	33	14	0
Totals.....	793	856	1004	1824	773	715	488	560	483	609	1471	4026	933	3314	
Total native species.....	606	762	827	1801	716	568	325	430	324	579	1425	1987	933	1779	
Averages of above.....	{	18	19	22	41	18	16	11	13	11	14	33	92	21	75
		14	17	19	42	16	13	7	10	7	13	33	45	31	40

Arranging these totals in series, we find that orchards stand at the top of both lists and stubble fields at the bottom, the former con-

taining nearly nine times as many birds per square mile as the latter if the English sparrows are counted, and about six times as many if they are not. Fields in crops of wheat, rye, barley, oats, or corn, and those from which the small grains have been harvested, are the least attractive to birds of all the situations listed, their numbers of native species per square mile ranging from 324 to 579, while the other areas rise from 716 for waste and fallow to 1987 for orchards.

We further notice that our two series do not differ materially in respect to the order of abundance, the dropping out of English sparrows having the effect only to shift six of the habitat names one place up or down, and leaving the positions of seven of the thirteen unchanged.

BIRDS PER SQUARE MILE OF 44 OF THE ABUNDANT
SPECIES,
THE WHOLE STATE, SUMMERS OF 1907 AND 1909,
IN ORDER OF NUMBERS

All species		Native species	
Orchards	4026	Orchards	1987
Yards and gardens	3314	Swamps	1801
Swamps	1824	Yards and gardens	1779
Woods	1471	Woods	1425
Pastures	1004	Shrubs	933
Shrubs	933	Pastures	827
Meadows	856	Meadows	762
Waste and fallow	773	Waste and fallow	716
Wheat, rye, barley	715	Plowed ground	579
Plowed ground	609	Wheat, rye, barley	568
Corn	560	Corn	430
Oats	488	Oats	325
Stubble	483	Stubble	324

An inspection of our preceding general table (page 214) shows that some birds have but a single favorite haunt or set of closely related haunts, that others have two very different places of principal resort, and that still others have a wide and rather indiscriminate range of local preference. Thus the English sparrow is seen to be mainly a bird of the orchard and the yard and garden; the meadowlark of the meadow, pasture, and waste lands; the dickcissel of the meadow only; the prairie horned lark of pasture fields and plowed ground; the bobolink of swamp and meadow; the field sparrow of shrubbery, orchard, and woods; and other local concentrations within one situation may be readily made out for the blue jay, orchard oriole, indigo bunting, song sparrow, cardinal, catbird, green heron, downy woodpecker, crested fly-catcher, towhee, the two marsh wrens, the red-headed woodpecker, and the mockingbird; while a distinctly double or multiple local allegiance is

apparent in our records of the crow-blackbird, found especially abundant in swamps, corn fields, orchards, and yards and gardens, of the cowbird in wheat and yards and gardens, the mourning dove in wheat and orchards, the flicker in meadow, pasture, and woods, and the upland plover in meadow and plowed land. This seems, in most cases at least, mainly a matter of the relations of feeding and breeding places, identical for some birds and for others more or less separate and unlike.

If we may assume that the present meadows and woodlands most nearly resemble the primitive prairie and forest as homes and haunts of birds, we see that in bringing the last two under cultivation we have greatly diminished the areas most desirable to birds, and must have reduced the total number of birds accordingly except as these unfavorable effects may have been compensated by more favorable conditions established at other points.

Such compensation appears in the substitution of pastures for prairie, as may be seen by a comparison of a total of 1004 birds per square mile of pasture with that of 856 for meadow; and in the substitution of orchard for forest, the numbers of which per square mile (English sparrow excluded) are 1987 and 1425 respectively—gains of 17 per cent. in the first case and nearly 39 per cent. in the second.

By a more detailed comparison of our tabulated data, one habitat column with another, we may get more precise ideas of the apparent affiliation of habitats as related to birds. These affiliations may be inferred from an examination of the following table, made by dropping from each column of the preceding general table the numbers per square mile which are smaller than the general average for the habitat, those remaining showing the species which are equal to or greater than the habitat average for all the species.

It will be readily seen that this table is divisible vertically into three more or less definite areas or bands, made up respectively of (1) meadows, pastures, swamps, and waste and fallow lands, the nearest approach remaining to us of the primitive prairies of the state; (2) fields of cereal crops together with plowed and stubble fields which have lately borne them; and (3) areas of forest, orchard, and shrubbery to which the exceptionally and radically new habitat of yards and gardens may be appended as more nearly related here than anywhere else.* For convenience' sake these may be distinguished as pasture-meadow, cereal-crop, and tree-shrub associations; and the numbers of birds per square mile of each were as follows: cereal-crop, 602, pasture-meadow, 923, and tree-shrub, 3111, related to each other respectively as 1, 1.65, and 5.17.

By a more detailed comparison of our tabulated data, one habitat column with another, we may get more precise ideas of the apparent affiliation of habitats as related to birds. The cereal-crop area is evidently

* For more significant features of this relationship, see the detailed general table on the opposite page. 314

CONDENSED GENERAL TABLE WITH SUBSTITUTION OF AN ASTERISK FOR ALL NUMBERS
LESS THAN THE AVERAGE OF ALL BIRDS FOR THE HABITAT

Species	Meadows	Pastures	Swamps	Waste and fallow	Wheat, rye, barley	Oats	Corn	Stubble	Plowed ground	Woods	Orchards	Shrubby	Yards and gardens
English sparrow.....	94	177	*	57	147	163	130	159	30	46	2039	0	1535
Bronzed grackle.....	49	72	207	20	56	92	138	*	28	46	158	0	761
Meadowlark.....	194	151	*	142	47	50	*	89	21	0	*	21	*
Cowbird.....	*	55	0	*	121	11	88	*	49	34	*	27	524
Mourning dove.....	29	41	0	37	141	14	29	40	77	51	256	21	*
Dickcissel.....	100	*	*	29	27	28	*	*	0	*	*	*	*
Prairie horned lark.....	21	48	0	*	24	*	19	11	162	0	0	0	*
Bobolink.....	96	24	130	26	*	16	*	23	*	0	0	0	*
Flicker.....	31	47	0	*	*	*	*	*	0	97	*	0	*
Red-winged blackbird.....	41	33	1125	93	26	21	18	*	*	34	*	0	*
Robin.....	*	50	*	59	*	*	*	*	34	80	152	21	*
Field sparrow.....	*	28	0	47	*	*	*	*	*	131	190	254	*
Goldfinch.....	*	*	*	27	*	*	*	*	*	40	*	55	*
Red-headed woodpecker.....	*	26	0	*	*	*	*	*	*	51	*	34	*
Crow.....	*	*	*	*	21	12	*	11	0	63	*	21	*
Quail.....	*	*	76	27	*	*	*	*	34	212	41	*	*
Grasshopper sparrow.....	41	*	*	*	*	*	*	*	0	0	0	0	0
Brown thrasher.....	*	*	0	*	*	*	*	*	69	125	34	0	*
Kingbird.....	*	*	0	19	*	*	*	*	0	0	0	0	*
Barn swallow.....	*	23	0	*	*	*	*	*	0	0	0	0	*
Upland plover.....	25	*	0	0	*	*	*	*	34	0	0	0	*
Blue jay.....	*	*	0	*	0	*	*	*	0	194	114	34	*
Bluebird.....	*	*	0	*	*	*	*	*	15	46	*	27	*
Killdeer.....	0	*	*	*	0	0	0	0	58	0	0	0	*
Chimney swift.....	*	*	0	*	*	*	*	0	*	0	0	0	*
Vesper sparrow.....	*	*	0	*	*	*	*	*	*	0	0	0	*
Cliff swallow.....	*	*	0	0	*	*	*	12	0	0	0	0	*
Orchard oriole.....	*	*	0	*	*	0	*	0	0	0	120	*	*
Indigo bunting.....	*	*	*	*	*	*	*	*	0	51	*	82	0
Mockingbird.....	*	*	0	*	*	0	*	0	*	0	0	0	*
Lark sparrow.....	*	*	0	*	*	*	*	0	*	0	*	0	*
Song sparrow.....	*	*	*	*	*	*	*	*	0	0	*	*	*
Maryland yellow-throat.....	*	*	*	*	*	*	*	0	0	34	*	41	*
Wood pewee.....	*	*	*	*	0	0	0	0	0	63	*	0	*
Cardinal.....	*	*	0	*	0	0	0	0	46	*	41	0	0
Catbird.....	0	*	0	*	0	*	*	0	*	103	0	*	*
Green heron.....	*	*	46	*	0	0	0	0	0	*	0	0	0
Downy woodpecker.....	0	*	0	*	0	0	0	0	34	*	0	*	*
Crested flycatcher.....	0	*	0	0	0	0	0	0	68	*	21	*	*
Towhee.....	0	*	0	0	0	0	0	0	51	*	41	*	*
Yellow-breasted chat.....	0	*	0	*	0	0	0	68	0	*	68	*	*
Short-billed marsh wren.....	0	0	*	*	0	0	0	0	0	0	0	0	0
Long-billed marsh wren.....	0	0	46	*	0	0	0	0	0	0	0	0	0
Tufted titmouse.....	0	*	0	0	0	0	0	0	51	*	*	0	0
Averages.....	19	22	41	18	16	11	13	11	14	33	92	21	75

a derivative of the pasture-meadow association, differentiated to the advantage of the former, but to the detriment of the birds; and the ornithological preponderance of the tree-shrub association may be more clearly shown by a comparison with the first two associations thrown together as one, giving us an average of 762 birds per square mile for the combination against 3111 for the tree-shrub association. Otherwise stated, we have found the summer-time birds of Illinois more than

four times as abundant to the unit of area in the tree-shrub association as in the remainder of the state. In this connection, however, we must recall the fact that the woodland area of our survey is not the dense and full grown forest of the wilderness, but is rather to be taken as equivalent to the forest edge; and the further fact that the limited acreage of our tree-shrub formation, 880 acres in all as against 18,408 of the other habitats, has probably led to a certain concentration of the normal forest birds, and especially of those which nest in trees and shrubs and seek their food largely in the open fields.

As a most general outcome of this final discussion, we may conclude that the remaining birds of the Illinois wilderness have adapted themselves to civilization, and especially to agriculture and horticulture, not so much by a change of choice or of habits, as by searching out under the new conditions the places which most nearly resemble their original nesting sites and which offer them food the nearest to that which, by hereditary inclination, they were impelled to choose; that in pastures, orchards, and yards and gardens they have found situations more favorable, and in the vast areas devoted to the cereal crops less favorable, to their maintenance and multiplication than their original habitats; and that while certain species have suffered heavily, in some cases nearly or quite to extermination (mainly, however, by the deliberate acts of man), others have greatly increased in numbers, the numerical make-up of the bird population of the state having thus shifted its balance in response to an increase of some resources and a diminution of others. Their remarkable success in self-maintenance under changes of environment which, from their viewpoint, may be called revolutionary, is not due to any flexibility of organization and consequent power of physical adaptation to new conditions—for which, indeed, they are much too highly and rigidly specialized—but to their remarkable sensory endowment and unequalled powers of locomotion, by the use of which each species is enabled to search out and occupy the most satisfactory ecological situations still to be found in the area of its geographical distribution.

PLATE XXXV



Southern Illinois landscape near Cave in Rock, Hardin county. On the Ohio River—indistinctly seen at the extreme left.

PLATE XXXVI



Typical view in farming area of southern Illinois, Hardin county.

PLATE XXXVII



Typical central Illinois pasture near Ogden, Champaign county. Upland plover in this field.

PLATE XXXVIII



Boggy pasture, characteristic of lowland fields near marshes
in northern Illinois. Libertyville, Lake county.

PLATE XXXIX



Clover field, cut and pastured, near Midland City, Dewitt county, central Illinois, July 16, 1907. Containing red-winged blackbirds, robin, upland plovers, meadowlarks, prairie horned larks, and brown thrasher.

PLATE XL



Meadowlark, from life, April 1, 1907, near Bismarck, Vermilion county, central Illinois.

PLATE XLI



Meadowlark's nest with two eggs of the meadowlark and three of the cowbird, Urbana, Champaign county, central Illinois, May 20, 1908.

PLATE XLII



Meadowlark's nest and young, near Benton, Franklin county, southern Illinois, June 11, 1907.

PLATE XLIII



Meadowlark's nest and eggs, near Easton, Mason county, central Illinois,
May 1, 1907.

PLATE XLIV



Meadowlark's nest and eggs, near Urbana, Champaign county, central Illinois, May 30, 1907.

PLATE XLV



Meadowlark's nest and eggs, near Elkhville, Jackson county, southern Illinois, June 21, 1907.

PLATE XLVI



Meadowlark's nest and eggs, near Clinton, Dewitt county, central Illinois,
May 16, 1907.

PLATE XLVII



Nest and eggs of prairie-hen, near Clinton, Dewitt county, central Illinois.
A few yards from nest of meadowlark shown in preceding picture.

PLATE XLVIII



Typical oats field, Lee county, northern Illinois, August 7, 1907.

PLATE XLIX



Wheat field near Emery, Macon county, central Illinois, July 18, 1907.

PLATE L



Nest and eggs of red-winged blackbird, July, 1909.

PLATE LI



Nest and eggs of red-winged blackbird, in timothy meadow near Benton,
Franklin county, southern Illinois, June 4, 1907.

PLATE LII



Nest and four eggs of grasshopper sparrow in alfalfa field, Urbana,
Champaign county, central Illinois, May 27, 1907.

PLATE LIII



Typical Illinois corn field near Buffalo Hart, Sangamon county, central Illinois, July 24, 1907.

PLATE LIV



Nest and eggs of prairie horned lark in oats field near Ogden, Champaign county, central Illinois, May 28, 1907.

PLATE LV



Marsh near Davis Junction, Ogle county, northern Illinois, July 30, 1907.
Home of the short-billed marsh wren—of which young birds were seen
at this date. Bobolinks and red-winged blackbirds common here.

PLATE LVI



Tamarack swamp near Wauconda, Lake county, northern
Illinois, March 4, 1907.

PLATE LVII



Woodland forest near Mulkeytown, Franklin county, southern Illinois,
June 20, 1907. Wood thrush and towhee common. Great crested
fly-catcher, yellow-bellied cuckoo, cardinal, red-bellied
woodpecker, and tufted titmouse seen here.

PLATE LVIII



Bur oak woodland near Poplar City, Mason county, central Illinois, May 2, 1907. Prickly pears on the sandy soil. Field sparrow and towhee here.

PLATE LIX



Lowland forest near Cave in Rock, Hardin county, southern Illinois, July 1, 1907. Wood thrush and red-eyed vireo very common here.

PLATE LX



Mourning dove's nest and eggs, near Thompsonville, Franklin county,
southern Illinois, June 5, 1907.

PLATE LXI



Mourning dove's nest and eggs, near Mount Vernon, Jefferson county,
southern Illinois, June 14, 1907.

PLATE LXII



Mourning dove's eggs in old robin's nest, Olney, Richland county, southern Illinois, September 7, 1908.

PLATE LXIII



Mourning dove's nest and eggs near center of large corn field, July 16, 1907.

PLATE LXIV



Mourning dove's nest and two young, near Mount Vernon, Jefferson county, southern Illinois, June 14, 1907.

PLATE LXV



Shrubbery near Clinton, Dewitt county, central Illinois, April 26, 1907.

PLATE LXVI



Sassafras thicket near Golconda, Pope county, southern Illinois, June 28, 1907. Prevalent condition throughout this county. Maryland yellow-throat, indigo bunting, and field sparrow very common. Two adults and three young of Kentucky warbler seen in woods near by.

PLATE LXVII



Open woods and shrubbery near Mt. Carmel, Wabash county, southern Illinois, April 9, 1907. Near the limit of density permitting the counting of birds.

PLATE LXVIII



Old corn field near Farmer City, Dewitt county, central Illinois,
March 29, 1907. Prairie-hens flushed in this field,
and two mallard ducks arose near by.

PLATE LXIX



Southern Illinois fallow, June, 1909.

PLATE LXX



Fallow field near Tamaroa, Perry county, southern Illinois, June 19, 1907.
Meadowlarks abundant, two of their nests with eggs and one
with young found within fifty yards of each other.

STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION
DIVISION OF THE
NATURAL HISTORY SURVEY
STEPHEN A. FORBES, Chief

Vol. XIV.

BULLETIN

Article VII.

CODLING-MOTH INVESTIGATIONS OF THE
STATE ENTOMOLOGIST'S OFFICE

1915, 1916, 1917

BY
PRESSLEY A. GLENN



PRINTED BY AUTHORITY OF THE STATE OF ILLINOIS

URBANA, ILLINOIS
August, 1922

STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION
W. H. H. MILLER, *Director*

BOARD OF
NATURAL RESOURCES AND CONSERVATION
W. H. H. MILLER, *Chairman*

WILLIAM TRELEASE, *Biology*
JOHN M. COULTER, *Forestry*
ROLLIN D. SALISBURY, *Geology*
WILLIAM A. NOYES, *Chemistry*

JOHN W. ALVORD, *Engineering*
KENDRIC C. BABCOCK, *Representing the*
President of the University of Illi-
nois

THE NATURAL HISTORY SURVEY DIVISION
STEPHEN A. FORBES, *Chief*

(64922—1200—G-22)



PHILLIPS BROS.' PRINT.
SPRINGFIELD, ILLINOIS.

CONTENTS

	PAGE
Introductory statement	219
Definition of terms.....	219
General conclusions	221
Equipment and method of work.....	223
Large-cage series	227
Life-history series	228
Band-record series.....	231
Influence of climatic conditions on the egg, larva, and pupa of the codling-moth	231
Zones of temperature.....	232
General procedure in the study of temperature relations.....	233
Relation of temperature to development of the egg.....	234
Relation of temperature to development of the larva.....	239
Relation of temperature to development of the pupa.....	246
Conclusions from the foregoing discussion.....	252
Observations on the life history of the codling-moth in 1915, 1916, and 1917.....	253
Incubation period	254
Larval period:	
Transforming lavæ.....	254
Hibernating larvæ	255
Pupal period	256
Combined egg, larval, and pupal periods.....	256
Adult period	257
Total life-period	257
Oviposition	258
Relation of temperature to length of development period.....	258
Seasonal history of the codling-moth, 1915.....	259
Large-cage series	259
First generation, 1915.....	260
Second generation, 1915.....	261
Third generation, 1915.....	261
Band collections:	
Hibernating generation, 1914-1915.....	262
Collections made in 1915.....	262
Hibernation, 1915	263
Summary of the seasonal history, 1915.....	263
Records for other points than Olney.....	264
General remarks on the season.....	264

IV

	PAGE
Seasonal history of the codling-moth, 1916.....	265
Large-cage series	265
Hibernating generation, 1915-1916.....	265
First generation	265
Second generation	266
Third generation	266
Band-collections:	
Hibernating generation, 1915-1916.....	267
Collections made in 1916.....	267
Hibernation, 1916	268
Summary of the seasonal history, 1916.....	269
Records for several localities.....	271
Seasonal history of the codling-moth, 1917.....	272
Large-cage series	272
First generation	272
Second generation	273
Third generation	273
Band collections:	
Hibernating generation, 1916-1917.....	273
Collections made in 1917 (see Table 37).....	273
Summary of the seasonal history, 1917.....	275
Relation of temperature to the seasonal history of the codling-moth.....	275
Method of forecasting dates when the different stages of the several generations may be expected to appear at any given place in a normal season.	281
How to compute effective day-degrees.....	282
Relation of temperature to time when larvæ hibernate.....	283
Relation of humidity and evaporation to the development of the codling-moth	284
Spray program for the codling-moth.....	288
Figures (8), Graphs (7), Tables (51), Charts (3).	

ARTICLE VII.—*Codling-moth Investigations of the State Entomologist's Office, 1915, 1916, and 1917.* BY P. A. GLENN, Chief Inspector of the Division of Plant Industry, State Department of Agriculture.

INTRODUCTORY STATEMENT

To secure accurate data in regard to the life history and the seasonal history of the codling-moth in Illinois, and the relation of climatic conditions to the rate of development and the time of appearance of the various stages of the insect, an investigation was begun in the spring of 1915 under the direction of Doctor S. A. Forbes, then State Entomologist. The principal station was established at Olney in charge of the writer, at that time and during the whole period of this investigation on the staff of the Entomologist.* Other stations were at Ozark, about 80 miles south and 45 miles east of Olney, in charge of Mr. L. M. Smith; and at Plainview, 40 miles north and 100 miles west of Olney, and at Springfield, 70 miles north and 90 miles west of Olney, in charge of Mr. W. P. Flint.

The station at Olney was equipped with large, screen-wire cages covering entire trees, a field laboratory and all necessary small cages for the observation of individual insects in all their stages, a self-recording thermograph, a self-recording hygrograph, a Livingston porous cup atmometer for measuring evaporation and a rain gage (Fig. 8, p. 230), standard maximum and minimum thermometers, and a sling psychrometer for checking daily the records of the self-recording instruments. The other stations were provided with instruments for keeping a record of climatic conditions.

At Olney a continuous daily record was kept of the history of all the stages of the insect. At the other stations band records and other data were recorded such as would enable us to follow the main features of the seasonal history of the insect.

DEFINITION OF TERMS

To avoid confusion resulting from a misunderstanding of terms, the following definitions are given:

The term "stages of the codling-moth" refers to the four distinct periods in the life of the insect: the egg, the larva, the pupa, and the adult.

* As a consequence of the passage of the Civil Administrative Code in 1917, the writer was transferred to the State Department of Agriculture, and the major part of this report has been written since he became a member of this department, the State Entomologist's office having been by the same law merged in the Natural History Survey of the State, with Dr. Forbes as its chief. This double relation has not, however, affected the character of this report, which has been prepared under the supervision of Dr. Forbes, and with a view to its publication as a survey bulletin.

The term "generation" is used to designate a group of insects in all the four stages from egg to adult, all equally removed by descent from a given insect or group of insects, except that the term "hibernating generation" is used for all the insects which hibernate, regardless of the generations to which they belonged the preceding year.

The term "brood" is used to designate all the individuals of one of the stages of a generation, as, brood of eggs, brood of larvæ, etc. The terms "first brood", "second brood", and "third brood" are used to designate the eggs, larvæ, pupæ, or adults of successive generations.

The "theoretical zero of development" is the temperature at which development begins when the temperature is rising and at which it ceases when the temperature is falling.

The "degree of maximum rate of development" is the temperature at which development proceeds most rapidly.

The "day-degree" is the unit used for measuring accumulations of temperature, and is equivalent to a temperature of one degree maintained for 24 hours.

"Effective day-degrees" are day-degrees above the zero of development, after necessary corrections have been made for retardation due to temperatures above the degree of maximum rate of development. This correction is made by subtracting twice the day-degrees above the degree of maximum rate from the total day-degrees above the zero of development.

The codling-moth passes the winter in the larval stage. The overwintering larvæ belong principally to the second and third generations of the preceding year, but for convenience in discussing the seasonal history we designate them as the hibernating generation. The generations which descend from the hibernating generation are designated as the "first generation", the "second generation", etc. In accordance with the foregoing definitions we have the following relations of generations and broods:

The hibernating generation, consisting of
the hibernating larvæ,
the first brood of pupæ, and
the first brood of adults.

The first generation, consisting of
the first brood of eggs,
the first brood of larvæ,
the second brood of pupæ, and
the second brood of adults.

The second generation, consisting of

the second brood of eggs,
the second brood of larvæ,
the third brood of pupæ, and
the third brood of adults.

The third generation, consisting of
the third brood of eggs,
the third brood of larvæ, etc.

In the case of insects which pass the winter as adults, the number of the broods will agree with the number of the generations to which they belong, but in the case of those that pass the winter in the egg, larval, or pupal stage, these numbers will not agree in all the broods.

GENERAL CONCLUSIONS

The following conclusions have been reached as the results of this investigation:

There are normally in the southern half of the state one complete generation, a nearly complete second generation, and a partial third generation of the codling-moth each year. In the northern part of the state there are but two generations.

In the latitude of Olney, larvæ of the first generation normally begin to enter the fruit about May 19; larvæ of the second generation, July 4; and larvæ of the third generation, August 12.

The data at hand are not sufficient to enable us to say definitely just how much allowance must be made in the time of appearance of the broods for differences of latitude, but in general, the first pupæ, moths, eggs, and young larvæ appear two or three days earlier at Ozark and two or three days later at Springfield than at Olney; and second and third broods of larvæ appear about a week earlier at Ozark and a week later at Springfield than at Olney.

The pupal period varies from 8 to 46 days, depending mainly upon the temperature. The period of the first brood is much longer than that of the second and third broods. The first brood period averages 30 days, the second 10.2 days, and the third 11.4 days.

The life of the male adult in confinement varies from 3 days to 24 days, the average being 10.5 days; the life of the female adult in confinement varies from 2 days to 27 days, the average being 13.4 days.

The female moth begins to lay eggs in from one to five days after emergence, the majority of the eggs being laid between the second and the fifth days, and oviposition is usually completed within ten days.

The egg period varies from 4 to 15 days, depending mainly upon the temperature. The average was 8.1 days for the 4956 eggs under observation.

The larval period varies from 18 to 47 days for transforming larvæ and from 244 to 302 for hibernating larvæ, the former averaging 26.4 days and the latter 264.8 days. The feeding period varies from 14 to 43 days for transforming larvæ and from 16 to 54 for hibernating larvæ, the average for the former being 24.7 and for the latter 29.3. The larval period in the cocoon varies for transforming larvæ from one to eleven days, and for hibernating larvæ from 206 to 275 days, the average for transforming larvæ being 4.2 and for hibernating larvæ 206.1 days.

The total life-period varies from 41 to 70 days for individuals whose larvæ transform, the average being 54.2, and from 287 to 332 days for individuals whose larvæ hibernate, the average being 313 days.

Larvæ begin to go into hibernation about August 1, and during the month the percentage of maturing larvæ which hibernate increases more or less rapidly, depending upon temperatures, until September 1, after which practically all larvæ hibernate.

Temperature is the predominating factor, so far as weather conditions are concerned, in determining the rate of development and the time of the appearance of the various stages.

Development begins in the spring as soon as the temperature in the warmer parts of the day rises above 52 degrees F., and the rate of development increases as the temperature rises,* until the degree of the maximum rate of development is reached, which for the egg is about 88, for the larva 85, and for the pupa 87 degrees F. The pupa will not develop at temperatures below 52 degrees, but the egg and larva will develop at temperatures above 50.

Temperatures above the degree of maximum rate of development retard development, and the retardation appears to be proportional to the number of degrees above the degree of the maximum rate, so that the rate of development at one, two, three, etc., degrees above the degree of the maximum rate is the same as one, two, three, etc., degrees below that degree.

There is a fairly constant relation between the accumulation of effective day-degrees and the time of appearance of the different broods. For practical purposes, 50 degrees F. may be used as the zero of development and 86 degrees as the degree of maximum rate of development, and the effective day-degrees for any day may be determined by finding the average temperature above 50 degrees and subtracting from it twice the average temperature above 86 degrees.

It requires an average of 163, 673, and 265 effective day-degrees to complete the development of the egg, larval, and pupal stages, respectively, and an average of 1101 for the development of an individual through the three stages when 50 is taken as the zero of development and 88, 85, and 87 as the degrees of maximum rate of development for the egg, larva, and pupa, respectively. The number of effective day-degrees which accumulate from a certain stage in the development of one generation to the same stage in the development of the succeeding generation varies in round numbers from about 1000 to 1600, the average being about 1195, when 50 is taken as the zero and 86 as the degree of maximum rate.

The first larvæ of the first, second, and third generations enter the fruit when the accumulations of effective day-degrees have reached about 550, 1550, and 2550 day-degrees, respectively.†

The seasonal history of the codling-moth for a normal year may be determined approximately in any locality by ascertaining the normal total accumulation of effective day-degrees for each day in the season in that locality.

* This statement is not strictly true, for with each unit of change in temperature, the rate of development is affected more at temperatures near the zero of development, and less at temperatures near the degree of maximum rate of development than at intermediate temperatures, but these variations from the rule are so slight that they may be disregarded for the purposes of this paper.

† The statements with regard to temperature relations may possibly not apply to places differing widely in latitude or altitude from Olney, Illinois.

The actual accumulation for any date during different seasons may vary widely from the normal accumulation.

By comparing the actual accumulation at any date during a given season with the normal accumulation for that date, the approximate number of days which development has been retarded or hastened on that date may be determined; and, by keeping track of the number of effective day-degrees that accumulate as the season advances, one may foretell, approximately, several days in advance, the dates when the larvæ of the different generations will begin to enter the fruit.

EQUIPMENT AND METHODS OF WORK

Aside from the large cages and the weather instruments previously mentioned, cages were devised for observing pupation of larvæ, emergence of moths, oviposition, and length of life of adults.

For observing pupation, cages such as those illustrated in Figures 1 and 2, were found to be most satisfactory. They consisted of two blocks of wood and a strip of celluloid, each $4\frac{3}{4}$ inches long and $2\frac{1}{2}$ inches wide. On the face of one of the blocks, strips of wood or heavy paper about $\frac{1}{8}$ inch thick were tacked along the end and longitudinally through the middle of the block, to hold the blocks far enough apart to permit the larvæ to crawl in between them. A strip of corrugated straw-board split through the middle so as to leave half of the corrugations on each face was placed, with the split surface up, on the block on each side of the center strip so as to cover the remaining face of the block. The other block was placed on the top of this with a strip of celluloid between, and the blocks were held together by small hooks and eyes fastened to the edges of the block, or by rubber bands—the latter proving the more satisfactory. There was room in each cage for about 50 larvæ. Smaller cages for single larvæ or a small number of larvæ were made on the same principle without blocks of wood.

When it was desired to determine the dates of pupation of larvæ collected from bands, they were confined in a lantern globe with one or more of the larger pupa-cages. Thus enclosed, the larvæ crawled into the little cells and spun their cocoons, and were thus arranged in very convenient order for further observation. By the use of sandpaper, the celluloid was roughened longitudinally through the center of the block, and after the larvæ were settled the number of each was entered on the celluloid beside it. (Fig. 2.)

Usually, transforming larvæ spun so thin a web on the exposed side of the cocoon that pupation could be observed without disturbing them, but hibernating larvæ spun a thicker web, and to observe them it was necessary to tear away a part of the web next to the celluloid every time an observation was made. The most convenient instrument for doing this was a steel crochet-needle with the hook ground away so as to leave only a small part of the barb. The cages above described will be referred to as pupa cages.

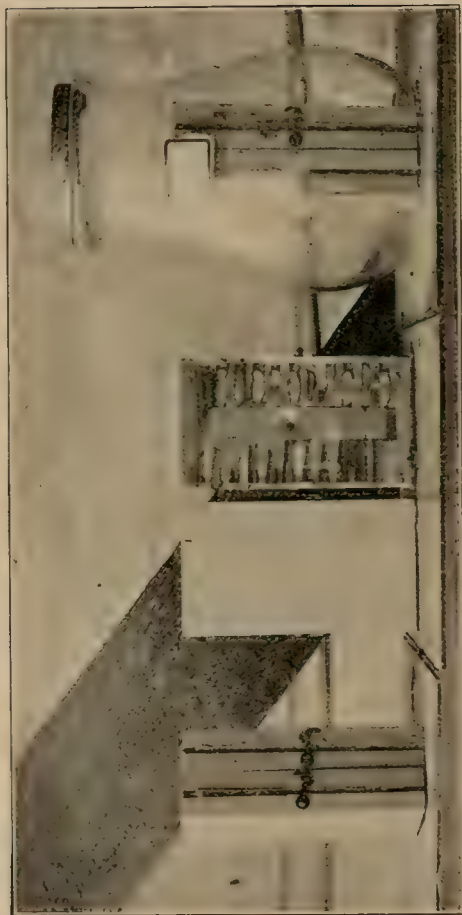


FIG. 1. Pupa cages: two at the left closed; one in the center open; and two in lantern globe.

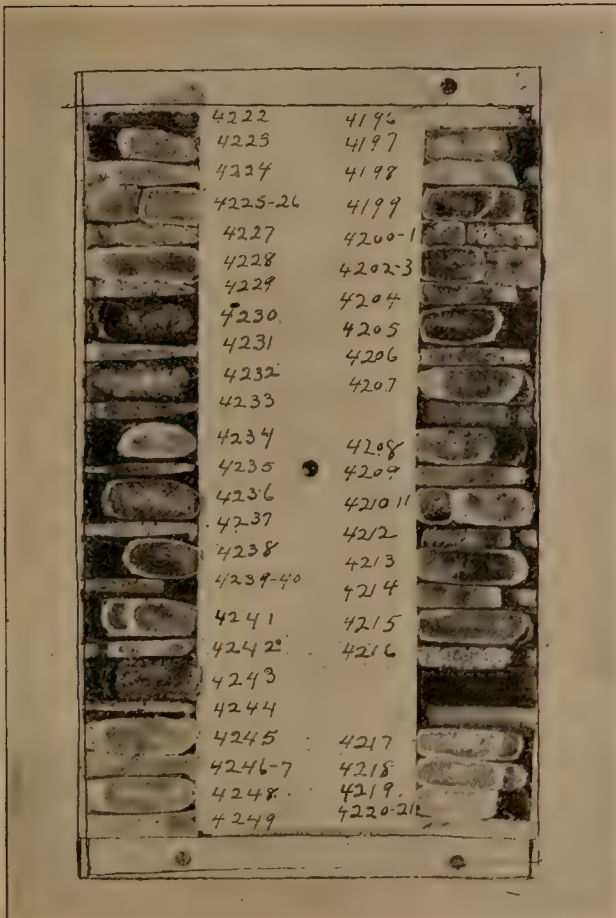


FIG. 2. Pupa cage open, showing arrangement of larvæ and method of numbering.

When it was desired to observe only the emergence of moths, larvæ were placed in a 4-oz. condiment jar containing a bundle of strips of strawboard. (Fig. 3.) These cages will be designated as emergence cages.



FIG. 3. Emergence cages. Strips of strawboard removed from jars to show arrangement of cocoons and pupa cases.

To secure eggs and note length of life of adults, pairs of moths were confined in cages consisting of a cylinder of screen-wire closed at one end with screen-wire and at the other end with an apron of cheese-cloth which permitted the cage to be fastened over the top of a branch of a tree. (Fig. 4.) These will be called oviposition cages.

The experiments were carried on in three series, kept as nearly independent as possible so that each would serve as a check on the others. I shall designate them as the *large-cage series*, the *life-history series*, and the *band-record series*.



FIG. 4. Two oviposition cages in place on tree.

LARGE-CAGE SERIES

Cages used in this series were large enough to cover entire trees, the largest cages being 18 feet square and 18 feet high. (Fig. 5, 6, and 7.) The plan was to use two cages each for the first and the second generations and one cage for the third generation—if a third generation appeared.

The framework of the cages, consisting of 2×4 scantling, was erected over the trees before they were in bloom, and wire cloth, 12 wires to the inch, was tacked over the frame as soon as the time of full bloom was past. Each of the cages had a tight-fitting screen-door provided with hasp and padlock.

The trees thus screened in were examined very carefully for larvæ and two inches of the soil in each cage was removed.

The first moths to emerge from the hibernating larvæ were placed in cage No. 1, and the last moths to emerge in cage No. 2, to rear the first and the last individuals of the first generation; the first moths reared

in cage No. 1 were liberated in cage No. 3 and the last moths reared in cage No. 2 were liberated in cage No. 4, to rear the first and the last individuals of the second generation; and the moths reared in cage No. 3 were liberated in cage No. 5, to rear the third generation. In this way it was possible to ascertain approximately the dates when each generation began and ended.



FIG. 5. Large screen-cage in course of construction.

LIFE-HISTORY SERIES

In the life-history series, pairs of adults of each of the broods were enclosed in oviposition cages (Fig. 4), and the number of eggs laid daily by each female and the dates of the death of the adults were noted.

The eggs obtained were numbered and allowed to remain on the trees until the black spot appeared. They were then removed to small vials on the bits of leaf or bark on which they had been laid, and, as they hatched, the larvæ were transferred to apples with a camel-hair brush, some to apples on the trees and others to picked fruit. The apples were tagged and each was given a number corresponding to that of the egg, and when they showed conspicuous signs of worminess they were transferred to jars, in which were placed strips of corrugated strawboard or small pupal cages in which the larvæ might spin up. The dates were noted when the larvæ left the apple, when they pupated, and when the adults emerged.



FIG. 6. View of orchard showing screened trees.

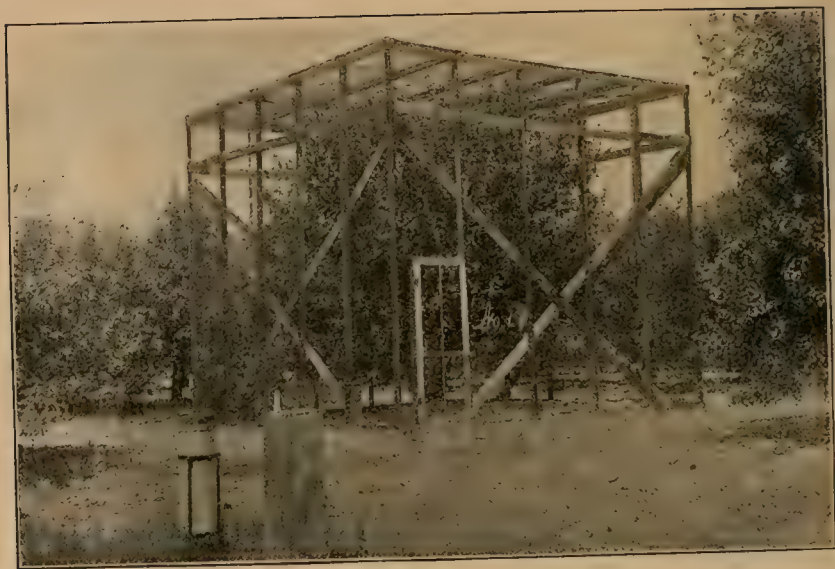


FIG. 7. Large cage completed. Rain-gage and atmometer in foreground.

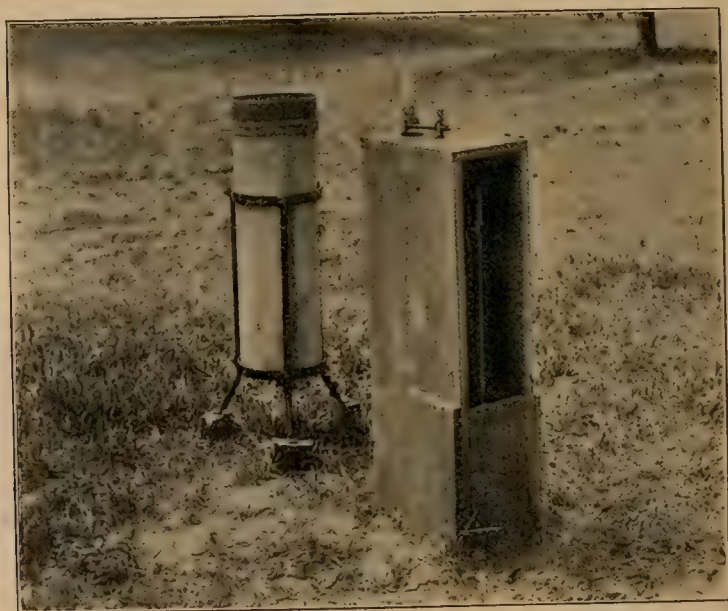


FIG. 8. Rain-gage (left), and atmometer (right) for determining rate of evaporation.

BAND-RECORD SERIES

A number of trees were banded each year at each of the places where observations were made, both sprayed and unsprayed trees being usually included. The bands used were mostly two or three-ply burlap, about 4 inches wide. They were placed on the trees about June 1 and examined every day until the first larvæ were found; and after that every third day. A record was kept of the number of male and female larvæ collected. All the larvæ collected were placed either in pupal cages or emergence cages for further observation, and a partial record of pupation and a complete record of the emergence of moths were kept at Olney. In cases where both pupation and emergence were noted the pupal periods of those under observation were determined, and the data thus obtained were used in connection with studies on the influence of climatic conditions on the development of the pupa.

No attempt will be made to record all the details of each of these series, but the combined results of all of them have been used in our studies on climatic relations, life history, and seasonal history. Since a knowledge of the influence of climatic relations will assist in interpreting our life-history and seasonal-history data, a discussion of the climatic influence will be taken up first.

INFLUENCE OF CLIMATIC CONDITIONS ON THE EGG, LARVA,
AND PUPA OF THE CODLING-MOTH

We ascertained by observations during 1915, 1916, and 1917, that the incubation period varied from 4 to 15 days, the pupal period from 7 to 46 days, and the larval period from 18 to 45 days, and that the time of the appearance of the first brood of larvæ may vary as much as 19 days, and of the second brood 7 or 8 days in different seasons in the same locality, and that the variation in the time of the same events in various parts of the state in the same season may be as much as 20 or 25 days. These variations in length of the periods and dates of appearance of the broods are due principally to climatic conditions, and especially to temperature. It is the purpose of the present study to ascertain the relation of climatic conditions to the rate of development and to the time of the appearance of the broods and, as far as possible, to suggest methods by which these relations may be turned to practical account.

Under out-of-door conditions, temperature is the predominating factor in determining rate of development of the codling-moth. Evaporation and humidity have so little influence that they may be disregarded, except, perhaps, in seasons when there are prolonged periods of extremely high or low humidity.

The influence of temperature will be considered first.

The fact that a certain degree of warmth is necessary for development of animal and vegetable life and that the rate of development is hastened by warm weather and retarded by cool weather has apparently always been known, but it is only within recent years that efforts have been made to ascertain the relative effects of different degrees of temperature.

ZONES OF TEMPERATURE

The entire range of temperature may be divided into six zones with respect to life and development, as shown below:

	Zone 6	Fatal temperatures; fatality due to heat.
Minimum high fatal degree		
	Zone 5	Estivation temperatures; not fatal, but unfavorable for development.
Zero of estivation		
	Zone 4	Temperatures stimulating development, the rate of development decreasing as the temperature rises.
Degree of maximum rate of development		
	Zone 3	Temperatures stimulating development, the rate of development increasing as the temperature rises.
Zero of development		
	Zone 2	Hibernating temperatures; not fatal, but unfavorable for development.
Maximum low fatal degree		
	Zone 1	Fatal temperatures; fatality due to lack of heat.

The limits of these zones differ for different species, for different stages of the same species, and for different phases of the same stage of the same species.

The limits of the zones of temperature of a species will be affected by the latitude to which it is acclimated, and it is possible that they will vary for individuals of the same species which are acclimated to different latitudes. Generally speaking, the limiting temperatures of the zones of species in low latitudes may be expected to be higher than of species in higher latitudes. The temperature at which an insect comes out of hibernation is in many cases quite different from that at which it becomes dormant in the latter part of the season, because heredity has an important influence in determining the time when insects begin the dormant period which lasts through the winter.

The temperatures on which these studies are based fall within zones 2, 3, and 4, the purpose being to determine for the codling-moth the zero of development, or the point at which development begins in spring as

the temperature rises; the degree at which development proceeds most rapidly; and to find a temperature constant for each of the stages and for the whole period of development which will apply to all temperatures, and a method by which that constant can be determined.

Before proceeding very far it was discovered that the character of the climatic data obtained under field conditions was not well suited to studies of this kind, because the temperature varied constantly throughout the day, and consequently the deductions had to be made from averages of widely varying degrees of temperature. Early in the season the temperature during part of the day was in the zone of hibernating temperatures and during the remaining time in the zone of temperatures which stimulated development, and later in the season the temperatures during part of the day were in the zone in which the rate of development increased as the temperature rises and during the remainder of the day in the zone in which the rate of development decreased as the temperature rises. For scientific accuracy it is of interest to determine the relative effects of each degree of temperature, but from data of the kind here used this could not be undertaken.

It has already been pretty well established that the rate of development increases, approximately at least, as the temperature rises above the zero of development, until the temperature at which the rate of development is at its maximum is reached; and our studies have led us to conclude that as the temperature rises above the degree of the maximum rate of development the rate of development decreases directly as the temperature rises.

The day has been used as the unit of time, and the day-degree as the unit of accumulated temperatures; and it has been assumed that, within certain limits of temperature, the period expressed in days multiplied by the average daily day-degrees above the zero of development will approximate a constant, or at least that the average products of a large number of observations will approximate a constant.

GENERAL PROCEDURE IN THE STUDY OF TEMPERATURE RELATIONS

The first step taken was to prepare temperature tables from the thermographic records, showing the mean daily temperatures. In computing the mean daily temperatures, the day was regarded as beginning and ending at 5 o'clock p. m., that being the hour when observations for the day usually ended. All mean daily temperatures were ascertained by dividing the sums of the temperature readings for the even hours of the day by 12. Mean temperatures above 50, 52, 85, 86, 87, and 88 degrees were computed in the same way.

The second step was to tabulate in detail all the data relative to the length of the egg, pupal, and larval periods, tabulating the data for each generation and year separately and arranging the data in chronological order with respect to dates when the periods began and ended.

The average mean daily temperatures and the length of the periods were determined for each observation. In all the groups of eggs, larvæ, and pupæ which began their periods on the same date there was a considerable variation in the recorded length of the period of individuals, due, no doubt, partly to the fact that individuals differ somewhat in respect to the amount of time required for them to develop even under identical conditions as to heat, light, moisture, and environment; and partly to errors of observation due for the most part, especially in case of eggs and pupæ, to the use of the day as the unit of time, on account of which the recorded period may, if the observations are made at the same hour each day, be almost a day longer or shorter than the true period, and, if the observations are not made at the same hour, the recorded period may be more than a day longer or shorter than the true period.

To avoid these variations the observations beginning on the same dates were thrown into groups, and the average period and average mean daily temperature were determined for each group. These smaller groups were then thrown into larger groups, using the mean daily temperature as the basis, all those passing through the period at an average mean daily temperature of 60 and 61 degrees or fraction thereof forming one group, and those passing through the period at temperatures of 62 and 63 degrees or fraction thereof forming another group, etc. The mean daily temperatures and the average length of the periods of these groups were then computed. All averages are weighted and all periods were averaged harmonically.

The detailed tables which it was necessary to prepare for the purpose of making the computations are voluminous and would not be of special interest. Only summaries made as above indicated will be given.

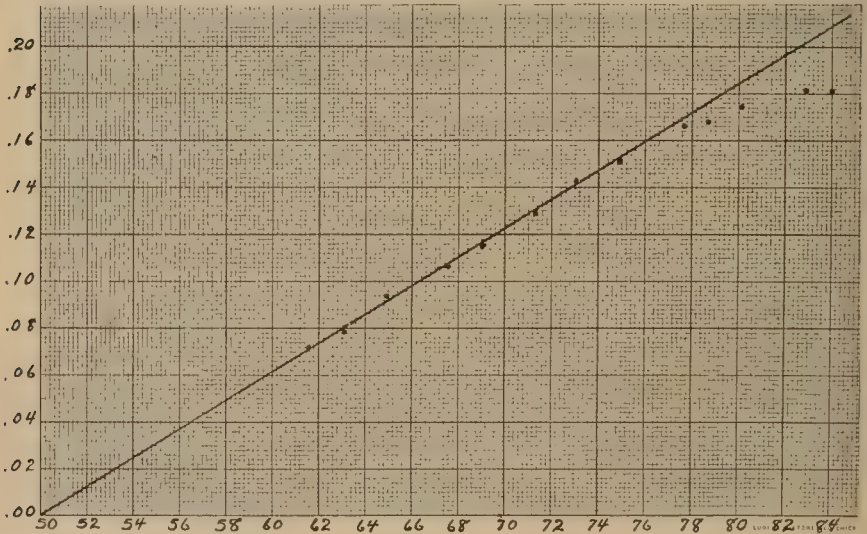
The reciprocal curve was used, with the mean daily temperature for the horizontal axis and the reciprocals of the periods for the vertical axis, to help locate approximately the zero of development and the degree of maximum rate of development; but this had to be supplemented by other methods on account of the displacement of points at the upper and lower ends of the line because of temperatures above the degree of the maximum rate of development and temperatures below the theoretical zero.

RELATION OF TEMPERATURE TO DEVELOPMENT OF THE EGG

The eggs used for observation were obtained from pairs of moths isolated on branches of trees in small wire cages. These cages were examined morning and evening. The day was used as the unit of time. Eggs found in the cages in the morning were recorded as having been laid the preceding day and those found in the afternoon were recorded as having been laid the same day. It is possible, therefore, that in some cases the recorded length of the period may be either almost a day longer or shorter than the actual period, but the averages of a large number of observations should approximate the true period very closely.

Table 1 is a final summary of the data on the relation of temperature to development of the egg. For the present we are concerned only with columns 4 and 5—the reciprocals of the periods and the average mean daily temperatures.

In preparing Graph 1, convenient fractional parts were laid off on the vertical axis corresponding to the reciprocals of the periods and divisions were made on the horizontal axis corresponding to the mean daily temperatures, and the one was plotted against the other.



GRAPH 1. Incubation period. Reciprocals of the periods plotted against average mean daily temperatures.

The points below 76 degrees fall approximately in a straight line, those above 76 are displaced to the right because for part of the time during the periods the temperature was above the degree of maximum rate of development. The reciprocal curve determined by the points below 76 degrees crosses the temperature axis at 49.32 degrees. Since it is probable that some of these points used are somewhat displaced, the upper ones somewhat to the right on account of temperatures higher than the degree of maximum rate of development, the lower ones to the left on account of temperatures below the zero of development, this line is probably a little too flat and the true line will cross the temperature axis above 49.32° rather than below it. Fifty degrees was taken as the approximate zero and was found to be nearly correct.

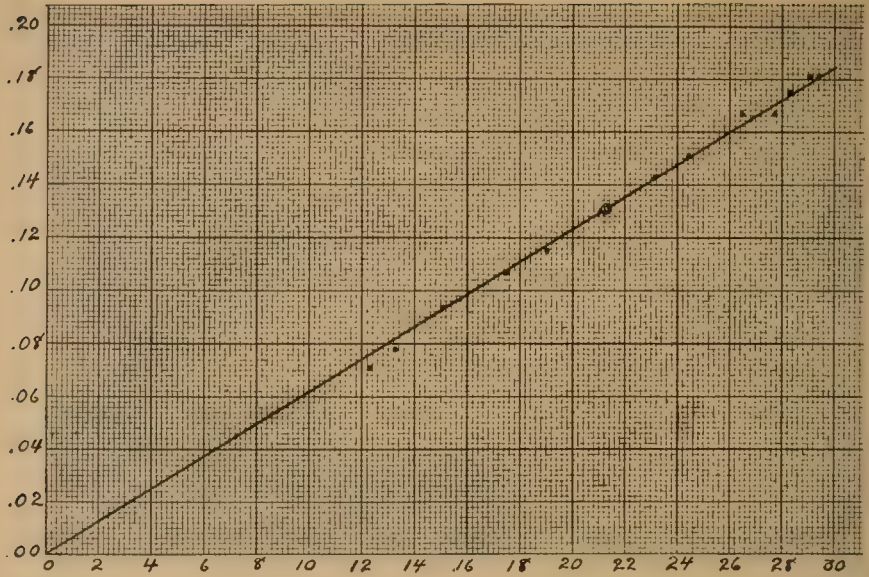
The average daily day-degrees above 50 degrees were computed for the different groups, and the results are recorded in column 6 of Table 1. Next, the averages in column 6 were multiplied by the length of the

various periods (column 3) in order to get the total accumulation of day-degrees. These are recorded in column 9. If, in column 9, we disregard the accumulations for the first two groups at the top of the table, the accumulations are fairly constant till the 78-79 group is reached. Below this the accumulations rapidly increase, owing to the fact that the averages in column 6 contain some temperatures that are above the degree of the maximum rate of development and so retard development. It was necessary, therefore, to ascertain the degree of maximum rate of development, and to make the necessary corrections in the daily day-degrees column, so as to get only the *effective* day-degrees. In determining this point and making the correction, it was assumed that the products obtained by multiplying the average daily effective day-degrees by the periods would be nearly the same for all temperatures. It will not be necessary to give the details of the process by which the degree of maximum rate of development and the effects of temperatures above this point were determined. Suffice it to say that they were found by making guesses and testing the guesses out. It was found in this way that if 88 degrees were taken as the degree of maximum rate of development and twice* the number of day-degrees above this point (column 7) were subtracted from the average day-degrees above 50 degree, values for the daily effective day-degrees (column 8) were secured which when multiplied by the periods gave products that very nearly filled the conditions, giving about the same accumulation of effective day-degrees for the high temperatures as for the low.

By plotting the average daily day-degrees obtained in column 8 against the reciprocals of the periods, the points all fall somewhere near the established line (Graph 2). The average accumulation of effective day-degrees for the incubation period is, therefore, about 163.

No good reason can be assigned why the accumulations for the 60-61 and the 62-63 groups should be higher than the average unless it may have been that in assuming in 1915 that eggs found in the forenoon of one day were laid the previous evening, too long a period was assigned to many of them. The weather during the early part of 1915 was very cloudy and a larger per cent. of the eggs were laid during the daytime than in the other seasons.

* Twice the number of day-degrees above the degree of maximum rate of development is subtracted from the total day-degrees above the zero of development because one degree rise in temperature above the degree of maximum rate of development retards the rate of development at approximately the same rate as does one degree fall in temperature below this point.



GRAPH 2. Incubation period. Reciprocals of the periods plotted against average daily effective day-degrees.

TABLE 2---DISTRIBUTION OF THE EGGS AS TO NUMBER OF THE TOTAL EFFECTIVE DAY-DEGREES ACCUMULATED DURING THE OBSERVED PERIOD

Number of eggs	Range of effective day-degrees
35	119-128
29	129-138
1030	149-158
2163	159-168
745	169-178
171	179-188
2	189-198

The variations in the total of effective day-degrees in the cases of individuals shown in the above table arises from several causes. Some of the extreme variations resulted, no doubt, from inaccuracies in observations; but for the most part they resulted from the use of the day as the unit, from which cause the recorded period may exceed or fall short of the true period by almost a day. Since in midsummer the daily accumulations may reach 27 effective day-degrees, the variations from this cause alone may be from 136 to 190. The variations from this source are so large that they overshadow all the lesser ones and make it impossible to estimate the errors which probably arise from them. This source of error might have been avoided by using a smaller unit of time. There is also a difference in eggs as to the length of time required for the incubation period. Moisture, evaporation, and light also may have a slight influence on the rate of development.

It is probably true that variations arising from individual differences are comparatively slight and that the wide variations shown in the tables are due to the first two causes above mentioned. The extreme variations may therefore be regarded as of little significance and the average of the large number of observations may be relied upon as being approximately the true heat factor.

RELATION OF TEMPERATURE TO DEVELOPMENT OF THE LARVA

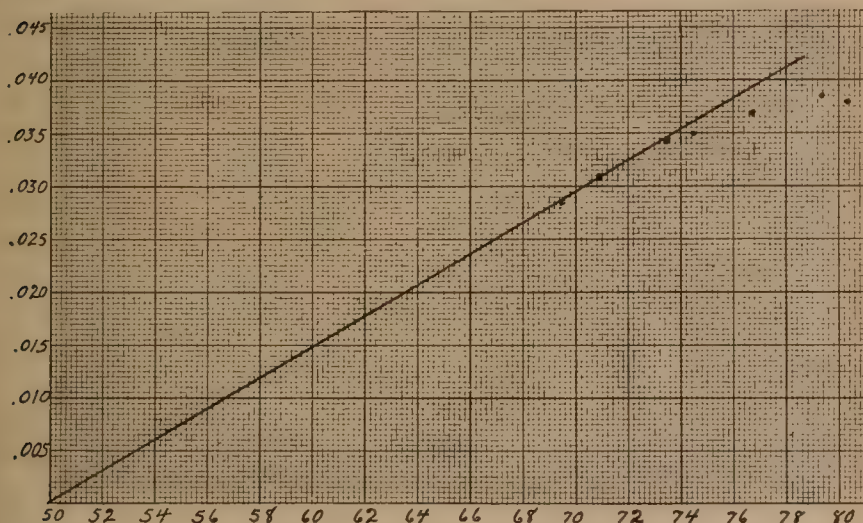
The conclusions arrived at are based upon observations made on 344 larvæ reared in apples on the tree and 214 larvæ reared in picked apples. It was found that larvæ reared in picked apples had a shorter period relative to the temperature than those reared in apples on the tree.

These data were first tabulated in detail and the periods and mean daily temperatures averaged for each of the observations, then for groups of larvæ which began the period on the same day, and lastly for groups arranged according to average mean daily temperatures. A summary of the results thus obtained from the observations on larvæ reared in apples on the tree is given in Table 3.

TABLE 3.—LARVAL PERIOD. SUMMARY OF DATA ON RELATION OF TEMPERATURE TO DEVELOPMENT. LARVAE REARED IN APPLES ON TREE.

Temp. range, deg. Fah.	Number of observa- tions	Harmonic average of periods in days	Recipro- cals of periods	Mean daily tem- perature	Daily day-degrees			Total day-degrees	
					50 +	2 (85 +)	$\frac{(50 +) -}{2(85 +)}$	50 +	$\frac{(50 +) -}{2(85 +)}$
68-69	32	35.57	.028531	69.45	19.45	.34	19.11	692	680
70-71	122	32.29	.03091	70.88	20.88	.30	20.58	674	665
72-73	45	29.20	.03424	73.48	23.48	.72	22.76	686	665
74-75	33	28.62	.03495	74.53	24.53	.74	23.79	702	681
76-77	14	27.14	.03684	76.74	26.74	1.40	25.34	726	688
78-79	20	25.93	.03855	79.39	29.39	3.62	25.77	762	668
80-81	78	26.33	.03798	80.30	30.30	4.36	25.94	798	683
68-81	344	29.07	.0338	74.31	24.31	1.56	22.75	719	673

In Graph 3, fractional parts corresponding to the reciprocals of the periods (Table 3) were laid off on the vertical axis, and divisions were marked on the horizontal axis corresponding to the mean daily temperatures. Points were then plotted, using the reciprocals of the periods and the mean daily temperatures as the coordinates.



GRAPH 3. Larval period. Reciprocals of the periods plotted against mean daily temperatures. Larvæ reared in apples on tree.

These points do not lie in a straight line, and hence can not be used for the purpose of establishing the reciprocal curve accurately. The points do not lie in a straight line because in making the mean daily averages temperatures were used which are not effective or which retard development. The lower points are less affected by this cause than the other points because they represent temperatures that are intermediate between the zero of development and the degree of the maximum rate of development. A straight line determined by the two lowest points crosses the temperature axis at 52+ degrees, a line determined by the three lowest points crosses the axis at 47+. All points between 47 and 52 were tried out as to which best fulfilled the condition as the zero of development and 50 was selected as the one which did so most nearly.

The daily day-degrees above 50 degrees were computed and the results were entered in column 6 of Table 3. The figures in this column multiplied by the number of days in the periods gave the total accumulations of day-degrees above 50 degrees, shown in column 9 of Table 3. An examination of these results as well as the position of the upper points in Graph 3 leads us to conclude that the gradual increase in the accumulations and the deviation to the right of the points from the line at the

higher temperatures were due to retarding temperatures or temperatures above the degree of maximum rate of development. To find this point guesses were made and tried out to test their correctness. It was found that by using 85 as the degree of the maximum rate of development, and subtracting twice the average day-degrees above 85 (column 7) from the day-degrees above 50, we got a temperature factor (column 8) for each of the temperature groups which when multiplied by the period expressed in days gave the most nearly constant products (column 10) for the different groups, the average for all groups being 673.

This average may be taken as the approximate average of accumulations of effective day-degrees for the larval period of larvæ reared in apples on the tree.

In Graph 4, the average daily effective day-degrees as recorded in column 8 of Table 3 were plotted against the reciprocals of the periods, with the result that the points in the upper part of the graph were brought nearly into line with the other points.



GRAPH 4. Larval period. Reciprocals of the periods plotted against mean daily effective day-degrees. Larvæ reared in apples on tree.

The data secured from observations made on 214 larvæ reared in picked apples were treated in the same manner as the data for larvæ reared in apples on the tree. A summary of the results is shown in Table 4.

TABLE 4—LARVAL PERIOD. SUMMARY OF DATA ON RELATION OF TEMPERATURE TO DEVELOPMENT. LARVAE REARED IN PICKED APPLES

Temp. range, deg. Fah.	Number of observa- tions	Harmonic average of periods in days	Recipro- cals of periods	Average mean daily tem- perature	Average daily day-degrees			Total day-degrees	
					50+	2(85+)	(50+)- 2(85+)	50+	(50+)- 2(85+)
66-67	1	34.00	.02941	67.90	17.90	.20	17.70	608	601
68-69	15	33.11	.03020	68.38	18.38	.26	18.12	609	600
70-71	63	28.94	.03456	71.25	21.25	.46	20.79	615	602
72-73	43	26.58	.03748	72.47	22.47	.50	21.97	599	586
74-75	27	22.84	.04378	74.82	24.82	.84	23.98	567	548
76-77	25	23.86	.04107	77.25	27.25	1.72	25.53	650	609
78-79	16	22.01	.04543	79.08	29.08	3.00	26.08	640	573
80-81	24	21.54	.04643	80.75	30.75	3.90	26.85	662	578
66-81	214	25.69	.03892	74.08	24.08	1.22	22.86	619	587

In computations for Table 4, 50 was taken as the zero of development and 85 as the degree of maximum rate of development. The results indicate that 52 degrees would have more nearly satisfied the conditions; but as the main interest in this table is that it gives an opportunity for comparing the rate of development of larvæ in apples on the tree and in picked apples, in order to have the same units of accumulation in both cases 50 was used as the zero. The average accumulation of effective day-degrees required to develop larvæ in picked apples was 587, or 86 day-degrees less than for larvæ in apples on the tree (Table 3).

The variations in the length of the larval period are very great for individuals even when subjected to the same conditions. The following example will illustrate the extent of the variations. Of 19 larvæ hatched July 20, 1916, one pupated in 20 days, two in 23 days, three in 25 days, one in 27 days, three in 28 days, four in 29 days, three in 30 days, one in 31 days, and one in 34 days, giving a variation of 14 days in the length of the period. Individual variations are also shown by the varying number of effective day-degrees which accumulated during the larval period.

Tables 5 and 6 show the distribution of larvæ as to accumulated effective day-degrees.

TABLE 5—DISTRIBUTION OF LARVAE REARED IN APPLES ON THE TREE WITH REFERENCE TO ACCUMULATED EFFECTIVE DAY-DEGREES DURING THE PERIOD

Number of larvæ	Range of effective day-degrees
8	456-499
18	500-549
39	550-599
65	600-649
64	650-699
58	700-749
29	750-799
26	800-849
16	850-899
6	900-949
1	950-969

The variations above 900 and below 500 are possibly due to errors in observations. The smaller variations are due in part to the use of the day as the period unit, and in part, no doubt, to the various temperatures

to which larvæ in different parts of the tree are simultaneously subjected, to variations in the character of food, and to individual differences. How much of the variations are attributable to each of these causes can not be accurately determined from the data at hand.

The use of the day as the unit will take account of a variation of 27 day-degrees each way from the average. If we assume that variations below 500 and above 900 are due to errors of observation and make a correction of 27 on account of the use of the day as the unit, it still leaves a variation of from 527 to 873 to be attributed to other causes. Since there is no way of eliminating these causes in practical operations, we must expect under natural conditions that some larvæ will complete their period when the effective day-degrees have reached 527 and that others will not complete it until 873 effective day-degrees have accumulated, the average accumulation being 673.

Table 6 shows the distribution of larvæ reared in picked apples as to total effective day-degrees required for their development.

TABLE 6—DISTRIBUTION OF LARVAE REARED IN PICKED APPLES WITH REFERENCE TO ACCUMULATIONS OF EFFECTIVE DAY-DEGREES DURING THE PERIOD

Number of larvæ	Range of effective day-degrees
3	400-449
16	450-499
41	500-549
59	550-599
40	600-649
22	650-699
12	700-749
5	750-799
1	800-849

Following the same course of reasoning with these data as with the preceding, the variations arising from factors which can not be eliminated under field conditions, range from 477 to 722, the average being 587.

These results are not very satisfactory for practical use. The averages are, no doubt, approximately correct; but the variations from the average are too great and the limits of the variations due to unpreventable causes are a little too uncertain to render the data entirely satisfactory for the purpose of forecasting life-history events. However, these are the nearest approximations to the actual accumulation of effective

day-degrees for the larva and the variations therefrom that we have at the present time, and with similar data for the egg and pupa they will serve as a fairly satisfactory basis for forecasting events in the seasonal history of the codling-moth.

RELATION OF TEMPERATURE TO DEVELOPMENT OF THE PUPA.

Observations were made on a total of 4348 pupæ of the codling-moth. The data were tabulated, grouped, and averaged in the same manner as those for the other stages. A summary of the results is given in Table 7.

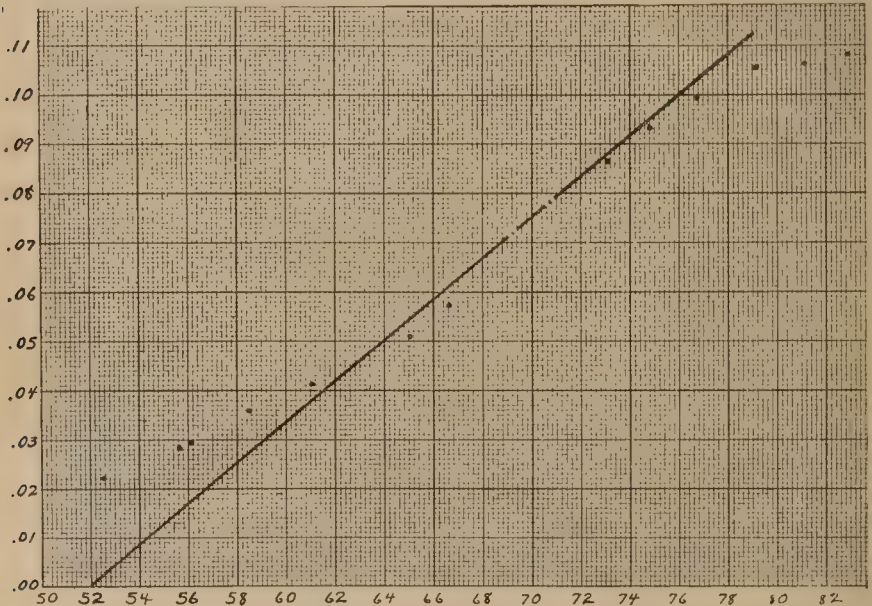
TABLE 7.—PUPAL PERIOD, OLNEY, ILLINOIS. SUMMARY OF DATA ON RELATION OF TEMPERATURE TO DEVELOPMENT

Temp. range, deg. F.	Number of observa- tions	Harmonic average of periods in days	Reciprocals of periods	Average mean daily temperatures	Average daily day-degrees				Total day-degrees		
					50 +	52 +	$\frac{2(87+)}{+}$	$\frac{(50+)-(52+)}{2(87+)}$	50 +	52 +	$\frac{(50+)-(52+)}{2(87+)}$
52-53	2	45.50	.0220	52.60	6.19	5.19	6.19	5.19	281.6	236.0	281.6
54-55	348	35.20	.0284	55.70	7.85	6.80	7.85	6.80	276.3	237.9	276.3
56-57	976	34.01	.0294	56.15	8.24	7.08	8.24	7.08	280.2	240.8	280.2
58-59	243	27.77	.0360	58.50	9.92	8.69	9.92	8.69	275.5	241.3	275.5
60-61	72	24.08	.0416	61.13	11.75	10.39	11.75	10.39	282.9	250.2	282.7
62-63	148	22.21	.0450	62.75	13.12	11.56	13.12	11.56	291.4	256.7	291.4
64-65	212	19.57	.0511	65.02	15.46	13.66	15.46	13.66	302.6	267.3	302.6
66-67	99	17.41	.0574	66.59	16.90	15.15	16.90	15.15	294.2	263.8	294.2
68-69	218	13.80	.0724	69.28	19.27	17.31	19.27	17.31	265.9	238.9	265.9
70-71	175	12.70	.0787	70.79	20.79	18.79	20.75	18.75	264.0	238.6	263.5
72-73	221	11.51	.0868	73.11	23.11	21.11	22.87	20.87	266.0	242.8	263.2
74-75	247	10.73	.0932	74.92	24.92	22.92	24.50	22.50	267.4	245.9	262.9
76-77	517	10.02	.0997	76.77	26.77	24.77	25.89	23.89	268.2	248.2	259.4
78-79	481	9.44	.1059	79.14	29.13	27.13	27.50	25.50	275.0	256.1	259.6
80-81	133	9.43	.1062	80.88	30.88	28.88	27.36	25.36	291.1	272.2	257.9
82-83	256	9.24	.1082	82.68	32.68	30.68	28.56	26.56	302.0	283.5	263.9
52-83	3817	14.49	.0690		19.03	17.38	.77	18.26	16.61	275.6	251.8
											240.7

N. B.—The totals and averages of this table do not include the data given for 60°-67° inclusive. The pupæ noted at those temperatures being a part of the hibernating generation which pupated late, were disturbed by daily examinations which resulted in a prolongation of the normal pupal period.

Graph 5 was prepared by plotting the reciprocals of the periods against the mean daily temperatures (columns 4 and 5, Table 7).

No three of the points in this graph appear to lie in a straight line. The points at the lower end of the line are too far to the left because in computing the mean daily temperatures temperatures below the zero of development were included, which prolongs the temperature axis too far to the left. Points at the upper end of the line are too far to the right because in computing the mean daily temperatures temperatures were included which were above the degree of the maximum rate of development and which, therefore, retarded development. The use of the mean daily degrees in this part of the graph prolonged the temperature axis too far to the right.



GRAPH 5. Pupal period. Reciprocals of the periods plotted against average mean daily temperatures.

The points from 60 to 68 degrees are lower than they should be normally because these represent the portion of the hibernating generation which did not pupate until from two to six weeks after pupation began in the spring, and were consequently disturbed daily until they pupated by having their cocoons torn open to make observations possible. The energy expended in repairing their cocoons daily seems to have devitalized them somewhat, on account of which a relatively longer period was required. Those which pupated last and hence were disturbed the most had the longest periods relative to the temperature. These points should, therefore, be disregarded.

Because all the points seem to be displaced more or less on account of using ineffective and retarding temperatures in the temperature axis, they afford no means of determining the true reciprocal curve. The two points that are least affected are the middle points from 68 to 72 degrees. The line determined by these two points cuts the temperature axis at 51.92 degrees. By using 50, 51, 52, and 53 degrees in turn as the possible zero of development it was found that 52 degrees more nearly satisfied the conditions than any other of the points.

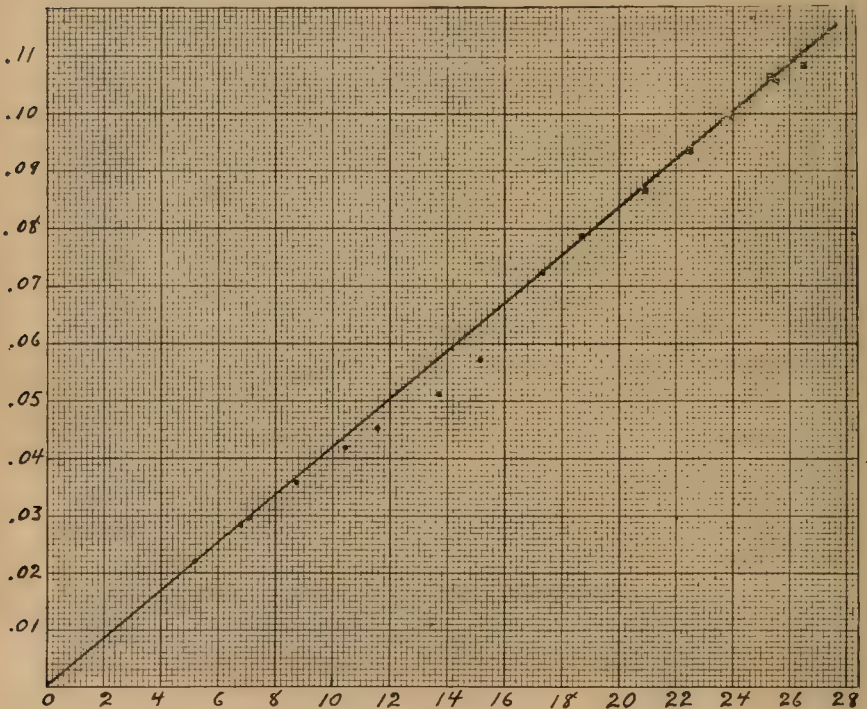
To ascertain the degree of the maximum rate of development 86, 87, 88, and 89 degrees were tried in turn. 87 most nearly satisfied the conditions.

The average daily day-degrees above 52 were computed and the results recorded in column 7 of Table 7. Twice the average daily day-degrees above 87 degrees were computed and the results placed in column 8. By subtracting twice the average day-degrees above 87 degrees from the average daily day-degrees above 52 degrees we got the average daily effective day-degrees in column 10. By multiplying the daily effective day-degrees by the periods, we obtained the total accumulated effective day-degrees recorded in column 14. It will be noted that with the exception of that portion of the hibernating generation which pupated late, between 60 and 67 degrees inclusive, the total effective day-degrees are quite uniform for all temperatures. The retardation of the late portion of the hibernating generation due to the daily disturbance to which they were subjected is shown by the increased accumulation which was necessary to bring them through the stage. We concluded, therefore, that the effective day-degrees for the pupa might be computed by subtracting from the sum of the average daily day-degrees above 52 degrees, twice the average daily day-degrees above 87 degrees. The average of the effective day-degrees as thus determined is 240.7.

Graph 6 was prepared by plotting the reciprocals of the periods against the average daily effective day-degrees given in columns 4 and 10 respectively of Table 7. It will be noted that all the points with the exception of those which represent the late portion of the hibernating generation (10-16) lie nearly in a straight line, which shows that there is a quite constant relation between the average daily effective day-degrees as above determined, and the rate of development.

Observations on the pupal period were made at such a wide range of temperatures that the data exemplify very nicely the hyperbolic form of the curve of development formed by plotting the periods against the average daily effective day-degrees. Graph 7 has been prepared to show the different positions of the points occasioned by the use of different factors as coordinates and also the curve of development.

Graph 7 combines Graphs 5 and 6, and also shows the curve of development. The circles show the position of the points when the reciprocals of the periods (Table 7, column 4) are plotted against the average mean daily temperature (column 5); the dots show the position of the points when the reciprocals of the periods are plotted against the average day-degrees above 52° (column 7); the dots with crosses show the position of the same points when the average daily effective

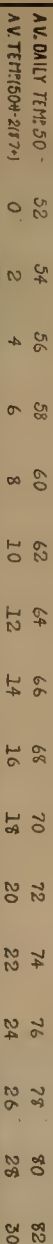


GRAPH 6. Pupal period. Reciprocals of the periods plotted against average daily effective day-degrees.

day-degrees after corrections were made for retarding temperatures above 87° (column 10) are substituted for the average mean daily temperatures in the temperature axis; and the concentric circles show the position of the same points when the periods in days are plotted against the average daily effective day-degrees.

The latter gives an hyperbola of which the equation is $EP=241$, in which E =average daily effective day-degrees and P =period in days.

PERIODS
RECIPROCAL



GRAPH 7. The time-temperature curve and different positions of points resulting from the use of different factors as coordinates, as indicated by the numerals under points.



There was a considerable variation in the observed length of periods of individual pupæ. Table 8 gives the distribution of pupæ with respect to the average accumulation of effective day-degrees of groups beginning the period on the same date.

TABLE 8—DISTRIBUTION OF PUPAE WITH RESPECT TO THE AVERAGE ACCUMULATED EFFECTIVE DAY-DEGREES OF GROUPS BEGINNING THE PERIOD ON THE SAME DATE

Number of pupæ	Day-degrees
1	166
1	185-194
4	195-204
3	205-214
110	215-224
602	225-234
2238	235-244
353	245-254
170	255-264
18	265-274
7	275-284
7	285-294
2	295-304

Recorded accumulations of less than 205 and more than 274 day-degrees are probably due to errors in observation. The lesser variations are probably due to individual differences, differences in humidity, and to the fact that the day was used as the unit in measuring time. The last factor mentioned may cause a variation of 27 from the average and is sufficient to account for nearly all of the variations. If we make a correction in the variation due to the use of the day as the unit, we still have left a variation of from 232 to 247 due to other causes, or a maximum difference of 9 from the average, which is 241.

In Table 7, I have also recorded the results obtained by using 50 as the zero of development. This was done in order that we might have as nearly as possible the same units for all three stages, when it was necessary to apply the data to the whole life period, and to the seasonal history. The average accumulation of effective day-degrees using 50 as

the zero of development is 265, and the variation due to causes other than the use of the day as the unit gives 256 as the minimum and 274 as the maximum.

CONCLUSIONS FROM THE FOREGOING DISCUSSION

1. There is a fairly constant relation between temperature and the rate of development of different stages of the codling-moth.
2. Only temperatures above the zero of development are effective.
3. The rate of development increases as the temperature rises above the zero of development until a temperature is reached at which the maximum rate of development takes place.
4. For the first few degrees, at least, above the degree of the maximum rate of development the rate of development decreases approximately as the temperature rises above this point.
5. The average daily effective day-degrees are found by subtracting from the average daily day-degrees above the zero of development twice the average daily day-degrees above the degree of maximum rate of development.
6. The product obtained by multiplying the average daily effective day-degrees by the period, expressed in days, or other convenient unit, is fairly constant for all temperatures.
7. Variations in the total accumulation of day-degrees recorded for individuals from the average accumulation, may result from the following causes:—1. Use of too large a unit of time. 2. Differences in humidity. 3. Individual differences. 4. Errors in observation. 5. Slight differences of temperature between the individual under observation and the recording instrument, due to difference of locality. 6. Abnormal environment and treatment of the individual.
8. The zero of development for the egg stage is about 50 degrees F. and the degree of the maximum rate of development is about 88. The equation of the curve of development is $PE = 163$, in which P = period in days, and E = average daily effective day-degrees.
9. The zero of development for the larva is about 50 degrees and the degree of the maximum rate of development is about 85 degrees. The equation of the curve of development for larvæ reared in apples on the tree is $PE = 673$; that for larvæ reared in picked apples is $PE = 587$.
10. The zero of development for the pupa is about 52 and the degree of maximum rate of development is about 87 degrees. The equation of the curve of development is $PE = 241$. For practical purposes it will be more convenient to use 50 as the zero of development for the pupa when applying the data to the whole life cycle, and the error that will result from so doing will amount to only a fraction of a day in the length of the period. The equation when 50 degrees is used, is $PE = 265$.

TABLE 15.—ITERITORY DATA ON PORTION OF SECOND GENERATION WHOSE LARVAE TRANSFORMED. OLYMPIA, 1915.

Life periods in days.

Total effective day-degrees.

TABLE 15.—LIFE-HISTORY DATA ON PORTION OF SECOND GENERATION WHOSE LARVAE TRANSFORMED. OLNEY, 1915.

TABLE 10—LIFE-HISTORY DATA ON FIRST GENERATION, OLNEY, 1916. LARVAE REARED IN APPLES ON TREE

[illegible]

SUMMARY OF TABLE 10

Sex.	Egg.		Larva in fruit.		Larva in cocoon.		Larva.		Pupa.		Egg, larva, and pupa.			Adult.		Total life period.	
	No.	Period in days.	No.	Period in days.	No.	Period in days.	No.	Period in days.	No.	Period in days.	No.	Period in days.	Total effective day-degrees (50+) Sum for stages.	No.	Period in days.		
M.	31	7.8	28	31.2	27	3.3	28	34.6	28	10.1	31	52.1	1127	1125	24	5.1	24
F.	34	7.8	30	31.0	30	3.6	32	35.1	32	9.8	34	52.7	1132	1131	29	6.9	29
M & F.	65	7.8	58	31.1	57	3.5	60	34.9	60	9.9	65	52.4	1129	1128	53	6.1	53

TABLE 15.—LIFE-HISTORY DATA ON PORTION OF SECOND GENERATION WHOSE LARVAE TRANSPORTED. OTTAWA, 1915.

TABLE 11.—LIFE-HISTORY DATA ON FIRST GENERATION, OLNEY, 1917. LARVAE REARED IN APPLES ON TREE

[illegible]

TAB. 15.—LITERATURE DATA ON PORTION OF SECOND GENERATION WHOSE LARVAE TRANSFORMED. OLYMP. 1915

[illegible]

Date	Egg hatch.	Larva hatched.	Larva pupated.	Adult emerged.	Adult died.	Life periods in days.					Total effective day-degrees.						
						Larva in cocoon.	Larval period.	Pupa.	Egg.	Total life period.							
May 21	28	June 24	June 28	July 8	July 12	7	27	4	31	10	48	4	52	165	548	263	976
" 21	" 28	" 24	" 28	" 10	" 16	7	27	"	"	"	"	"	"	165	548	263	976
" 21	" 28	" 24	" 29	" 9	" 16	7	27	"	33	10	50	"	"	165	548	263	976
" 21	" 28	" 28	" 30	" 11	" 16	7	30	"	34	11	52	5	56	165	548	263	976
" 21	" 28	" 27	July 1	" 12	" 18	7	30	"	26	10	46	8	56	165	548	263	976
" 21	" 28	" 29	" 3	" 13	" 19	7	30	"	24	10	46	8	56	165	548	263	976
" 21	" 28	" 7	July 1	" 5	" 15	7	30	"	24	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 2	" 6	" 15	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 3	" 7	" 17	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 4	" 8	" 18	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 5	" 9	" 19	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 6	" 10	" 20	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 7	" 11	" 21	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 8	" 12	" 22	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 9	" 13	" 23	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 10	" 14	" 24	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 11	" 15	" 25	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 12	" 16	" 26	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 13	" 17	" 27	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 14	" 18	" 28	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 15	" 19	" 29	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 16	" 20	" 30	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 17	" 21	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 18	" 22	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 19	" 23	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 20	" 24	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 21	" 25	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 22	" 26	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 23	" 27	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 24	" 28	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 25	" 29	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 26	" 30	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 27	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 28	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 29	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 30	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 31	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 32	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 33	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 34	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 35	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 36	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 37	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 38	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 39	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 40	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 41	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 42	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 43	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 44	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 45	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 46	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 47	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 48	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 49	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 50	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 51	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 52	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 53	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 54	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 55	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 56	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 57	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 58	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 59	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 60	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 61	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 62	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 63	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 64	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 65	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 66	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 67	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 68	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 69	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 70	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 71	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 72	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 73	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 74	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 75	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 76	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 77	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 78	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 79	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 80	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 81	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 82	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 83	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 84	" 31	" 31	7	30	"	23	10	46	8	56	165	548	263	976
" 21	" 28	" 7	" 85	" 31	" 31	7	30	"	23	10	46	8	56	165	5		

SUMMARY OF TABLE 12A

[illegible]

TABLE 15.—LIFE-HISTORY DATA ON PORTION OF SECOND GENERATION WHOSE LARVAE TRANSFORMED. ONEY, 1915.

TYPE	Length, mm.	Weight, mg.	Length, mm.	Weight, mg.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420	421	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442	443	444	445	446	447	448	449	450	451	452	453	454	455	456	457	458	459	460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480	481	482	483	484	485	486	487	488	489	490	491	492	493	494	495	496	497	498	499	500	501	502	503	504	505	506	507	508	509	510	511	512	513	514	515	516	517	518	519	520	521	522	523	524	525	526	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543	544	545	546	547	548	549	550	551	552	553	554	555	556	557	558	559	560	561	562	563	564	565	566	567	568	569	570	571	572	573	574	575	576	577	578	579	580	581	582	583	584	585	586	587	588	589	590	591	592	593	594	595	596	597	598	599	600	601	602	603	604	605	606	607	608	609	610	611	612	613	614	615	616	617	618	619	620	621	622	623	624	625	626	627	628	629	630	631	632	633	634	635	636	637	638	639	640	641	642	643	644	645	646	647	648	649	650	651	652	653	654	655	656	657	658	659	660	661	662	663	664	665	666	667	668	669	670	671	672	673	674	675	676	677	678	679	680	681	682	683	684	685	686	687	688	689	690	691	692	693	694	695	696	697	698	699	700	701	702	703	704	705	706	707	708	709	710	711	712	713	714	715	716	717	718	719	720	721	722	723	724	725	726	727	728	729	730	731	732	733	734	735	736	737	738	739	740	741	742	743	744	745	746	747	748	749	750	751	752	753	754	755	756	757	758	759	760	761	762	763	764	765	766	767	768	769	770	771	772	773	774	775	776	777	778	779	780	781	782	783	784	785	786	787	788	789	790	791	792	793	794	795	796	797	798	799	800	801	802	803	804	805	806	807	808	809	810	811	812	813	814	815	816	817	818	819	820	821	822	823	824	825	826	827	828	829	830	831	832	833	834	835	836	837	838	839	840	841	842	843	844	845	846	847	848	849	850	851	852	853	854	855	856	857	858	859	860	861	862	863	864	865	866	867	868	869	870	871	872	873	874	875	876	877	878	879	880	881	882	883	884	885	886	887	888	889	890	891	892	893	894	895	896	897	898	899	900	901	902	903	904	905	906	907	908	909	910	911	912	913	914	915	916	917	918	919	920	921	922	923	924	925	926	927	928	929	930	931	932	933	934	935	936	937	938	939	940	941	942	943	944	945	946	947	948	949	950	951	952	953	954	955	956	957	958	959	960	961	962	963	964	965	966	967	968	969	970	971	972	973	974	975	976	977	978	979	980	981	982	983	984	985	986	987	988	989	990	991	992	993	994	995	996	997	998	999	1000	1001	1002	1003	1004	1005	1006	1007	1008	1009	1010	1011	1012	1013	1014	1015	1016	1017	1018	1019	1020	1021	1022	1023	1024	1025	1026	1027	1028	1029	1030	1031	1032	1033	1034	1035	1036	1037	1038	1039	1040	1041	1042	1043	1044	1045	1046	1047	1048	1049	1050	1051	1052	1053	1054	1055	1056	1057	1058	1059	1060	1061	1062	1063	1064	1065	1066	1067	1068	1069	1070	1071	1072	1073	1074	1075	1076	1077	1078	1079	1080	1081	1082	1083	1084	1085	1086	1087	1088	1089	1090	1091	1092	1093	1094	1095	1096	1097	1098	1099	1100	1101	1102	1103	1104	1105	1106	1107	1108	1109	1110	1111	1112	1113	1114	1115	1116	1117	1118	1119	1120	1121	1122	1123	1124	1125	1126	1127	1128	1129	1130	1131	1132	1133	1134	1135	1136	1137	1138	1139	1140	1141	1142	1143	1144	1145	1146	1147	1148	1149	1150	1151	1152	1153	1154	1155	1156	1157	1158	1159	1160	1161	1162	1163	1164	1165	1166	1167	1168	1169	1170	1171	1172	1173	1174	1175	1176	1177	1178	1179	1180	1181	1182	1183	1184	1185	1186	1187	1188	1189	1190	1191	1192	1193	1194	1195	1196	1197	1198	1199	1200	1201	1202	1203	1204	1205	1206	1207	1208	1209	1210	1211	1212	1213	1214	1215	1216	1217	1218	1219	1220	1221	1222	1223	1224	1225	1226	1227	1228	1229	1230	1231	1232	1233	1234	1235	1236	1237	1238	1239	1240	1241	1242	1243	1244	1245	1246	1247	1248	1249	1250	1251	1252	1253	1254	1255	1256	1257	1258	1259	1260	1261	1262	1263	1264	1265	1266	1267	1268	1269	1270	1271	1272	1273	1274	1275	1276	1277	1278	1279	1280	1281	1282	1283	1284	1285	1286	1287	1288	1289	1290	1291	1292	1293	1294	1295	1296	1297	1298	1299	1300	1301	1302	1303	1304	1305	1306	1307	1308	1309	1310	1311	1312	1313	1314	1315	1316	1317	1318	1319	1320	1321	1322	1323	1324	1325	1326	1327	1328	1329	1330	1331	1332	1333	1334	1335	1336	1337	1338	1339	1340	1341	1342	1343	1344	1345	1346	1347	1348	1349	1350	1351	1352	1353	1354	1355	1356	1357	1358	1359	1360	1361	1362	1363	1364	1365	1366	1367	1368	1369	1370	1371	1372	1373	1374	1375	1376	1377	1378	1379	1380	1381	1382	1383	1384	1385	1386	1387	1388	1389	1390	1391	1392	1393	1394	1395	1396	1397	1398	1399	1400	1401	1402	1403	1404	1405	1406	1407	1408	1409	1410	1411	1412	1413	1414	1415	1416	1417	1418	1419	1420	1421	1422	1423	1424	1425	1426	1427	1428	1429	1430	1431	1432	1433	1434	1435	1436	1437	1438	1439	1440	1441	1442	1443	1444	1445	1446	1447	1448	1449	1450	1451	1452	1453	1454	1455	1456	1457	1458	1459	1460	1461	1462	1463	1464	1465	1466	1467	1468	1469	1470	1471	1472	1473	1474	1475	1476	1477	1478	1479	1480	1481	1482	1483
------	-------------	-------------	-------------	-------------	---	---	---	---	---	---	---	---	---	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------

TABLE 13.—OVIPOSITION AND LIFE PERIOD OF ADULTS OF FIRST GENERATION, ONETA, 1915.
AND WEATHER DURING FIRST TEN DAYS AFTER EMERGENCE OF FEMALE

Emergenc.		Died.		Days lived.		Number of eggs laid daily 1 to 9 days after emergence.									Av. mean daily temp.		Av. daily rainfall.
Male.	Female.	Male.	Female.	Male.	Female.	1	2	3	4	5	6	7	8	9	Total		
July 1	June 28	July 8	July 7	7	9	.....	.....	.....	55	.....	.....	.....	.....	.....	80	68.8	291
" 2	" 3	" 15	" 15	13	12	.....	.....	.....	.....	.....	.....	.....	.....	.....	43	68.9	40
" 4	" 4	" 14	" 14	10	10	.....	.....	.....	.....	.....	.....	.....	.....	.....	37	70.2	346
" 5	" 5	" 14	" 15	7	9	.....	.....	.....	.....	.....	.....	.....	.....	.....	35	72.3	346
" 7	" 7	" 13	" 16	6	8	.....	.....	.....	.....	.....	.....	.....	.....	.....	9	75.4	214
" 9	" 9	" 12	" 15	3	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	24	77.6	285
" 11	" 11	" 16	" 16	5	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	77	78.2	181
" 11	" 11	" 17	" 21	10	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	45	78.2	181
" 13	" 13	" 17	" 18	4	5	.....	.....	.....	.....	.....	.....	.....	.....	.....	1	77.0	106
" 15	" 15	" 20	" 20	5	5	.....	.....	.....	.....	.....	.....	.....	.....	.....	91	75.2	106
" 17	" 17	" 21	" 22	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	25	78.4	642
" 18	" 18	" 23	" 23	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	2	78.2	962
" 18	" 18	" 26	" 28	8	10	.....	.....	.....	.....	.....	.....	.....	.....	.....	9	73.5	962
" 20	" 20	" 26	" 26	6	6	.....	.....	.....	.....	.....	.....	.....	.....	.....	48	73.8	953
" 20	" 20	" 30	" 26	10	16	.....	.....	.....	.....	.....	.....	.....	.....	.....	1	73.8	953
" 22	" 22	" 26	" 26	4	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	32	75.2	116
" 23	" 23	" 26	" 26	11	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	78	75.4	130
" 27	" 27	" 31	" 31	4	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	11	73.2	110
" 27	" 27	" 31	" 31	11	6	.....	.....	.....	.....	.....	.....	.....	.....	.....	167	73.8	110
" 28	" 28	" 31	" 31	3	6	.....	.....	.....	.....	.....	.....	.....	.....	.....	1	70.3	164
" 29	" 29	" 31	" 31	2	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	45	70.3	164
" 5	" 5	" 12	" 13	7	8	.....	.....	.....	.....	.....	.....	.....	.....	.....	1	72.4	351
" 7	" 7	" 14	" 14	10	10	.....	.....	.....	.....	.....	.....	.....	.....	.....	4	72.4	351
" 9	" 9	" 14	" 14	14	5	.....	.....	.....	.....	.....	.....	.....	.....	.....	2	71.0	363
" 11	" 11	" 23	" 23	12	12	.....	.....	.....	.....	.....	.....	.....	.....	.....	2	69.6	359
" 11	" 11	" 23	" 23	6	7	.....	.....	.....	.....	.....	.....	.....	.....	.....	42	69.6	359
" 13	" 13	" 22	" 22	9	9	.....	.....	.....	.....	.....	.....	.....	.....	.....	7	69.4	359
" 14	" 14	" 22	" 22	15	15	.....	.....	.....	.....	.....	.....	.....	.....	.....	84	69.4	359
" 21	" 21	" 28	" 28	7	7	.....	.....	.....	.....	.....	.....	.....	.....	.....	64	64.5	406
Totals.		Totals.		Totals.		230	447	166	120	47	26	.....	.....	84	1170	.....	.....

SUMMARY OF TABLE 13

Items.

Max. Min. Av.

Length of life of male moth in days.....	14	3	7.2
Length of life of female moth in days.....	15	1	7.6
Number of days from emergence till egg-laying began.....	5	2	2.8
Number of days from emergence till egg-laying ceased.....	10	2	3.8
Egg-laying period in days.....	4	1	1.5
Number of eggs laid by one female.....	167	1	39
Average mean daily temperature.....	.....	.....	73
Average daily rainfall in inches.....	.....	.....	.24

TABLE 15.—LIFE-HISTORY DATA ON PORTION OF SECOND GENERATION WHOSE LARVAE TRANSFORMED, OLNEY, 1915.
LARVAE REARED IN APPLIES ON TREE

No.	Date	Length of life periods.	Total effective day-degrees.	No.	Date	Length of life periods.	Total effective day-degrees.
1	5-11	6	11	11	5-11	6	11
2	11-17	6	11	12	11-17	6	11
3	17-24	7	12	13	17-24	7	12
4	24-31	7	12	14	24-31	7	12
5	31-5	4	9	15	31-5	4	9
6	5-11	6	11	16	5-11	6	11
7	11-17	6	11	17	11-17	6	11
8	17-24	7	12	18	17-24	7	12
9	24-31	7	12	19	24-31	7	12
10	31-5	4	9	20	31-5	4	9
11	5-11	6	11	21	5-11	6	11
12	11-17	6	11	22	11-17	6	11
13	17-24	7	12	23	17-24	7	12
14	24-31	7	12	24	24-31	7	12
15	31-5	4	9	25	31-5	4	9
16	5-11	6	11	26	5-11	6	11
17	11-17	6	11	27	11-17	6	11
18	17-24	7	12	28	17-24	7	12
19	24-31	7	12	29	24-31	7	12
20	31-5	4	9	30	31-5	4	9
21	5-11	6	11	31	5-11	6	11
22	11-17	6	11	32	11-17	6	11
23	17-24	7	12	33	17-24	7	12
24	24-31	7	12	34	24-31	7	12
25	31-5	4	9	35	31-5	4	9
26	5-11	6	11	36	5-11	6	11
27	11-17	6	11	37	11-17	6	11
28	17-24	7	12	38	17-24	7	12
29	24-31	7	12	39	24-31	7	12
30	31-5	4	9	40	31-5	4	9
31	5-11	6	11	41	5-11	6	11
32	11-17	6	11	42	11-17	6	11
33	17-24	7	12	43	17-24	7	12
34	24-31	7	12	44	24-31	7	12
35	31-5	4	9	45	31-5	4	9
36	5-11	6	11	46	5-11	6	11
37	11-17	6	11	47	11-17	6	11
38	17-24	7	12	48	17-24	7	12
39	24-31	7	12	49	24-31	7	12
40	31-5	4	9	50	31-5	4	9
41	5-11	6	11	51	5-11	6	11
42	11-17	6	11	52	11-17	6	11
43	17-24	7	12	53	17-24	7	12
44	24-31	7	12	54	24-31	7	12
45	31-5	4	9	55	31-5	4	9
46	5-11	6	11	56	5-11	6	11
47	11-17	6	11	57	11-17	6	11
48	17-24	7	12	58	17-24	7	12
49	24-31	7	12	59	24-31	7	12
50	31-5	4	9	60	31-5	4	9
51	5-11	6	11	61	5-11	6	11
52	11-17	6	11	62	11-17	6	11
53	17-24	7	12	63	17-24	7	12
54	24-31	7	12	64	24-31	7	12
55	31-5	4	9	65	31-5	4	9
56	5-11	6	11	66	5-11	6	11
57	11-17	6	11	67	11-17	6	11
58	17-24	7	12	68	17-24	7	12
59	24-31	7	12	69	24-31	7	12
60	31-5	4	9	70	31-5	4	9
61	5-11	6	11	71	5-11	6	11
62	11-17	6	11	72	11-17	6	11
63	17-24	7	12	73	17-24	7	12
64	24-31	7	12	74	24-31	7	12
65	31-5	4	9	75	31-5	4	9
66	5-11	6	11	76	5-11	6	11
67	11-17	6	11	77	11-17	6	11
68	17-24	7	12	78	17-24	7	12
69	24-31	7	12	79	24-31	7	12
70	31-5	4	9	80	31-5	4	9
71	5-11	6	11	81	5-11	6	11
72	11-17	6	11	82	11-17	6	11
73	17-24	7	12	83	17-24	7	12
74	24-31	7	12	84	24-31	7	12
75	31-5	4	9	85	31-5	4	9
76	5-11	6	11	86	5-11	6	11
77	11-17	6	11	87	11-17	6	11
78	17-24	7	12	88	17-24	7	12
79	24-31	7	12	89	24-31	7	12
80	31-5	4	9	90	31-5	4	9
81	5-11	6	11	91	5-11	6	11
82	11-17	6	11	92	11-17	6	11
83	17-24	7	12	93	17-24	7	12
84	24-31	7	12	94	24-31	7	12
85	31-5	4	9	95	31-5	4	9
86	5-11	6	11	96	5-11	6	11
87	11-17	6	11	97	11-17	6	11
88	17-24	7	12	98	17-24	7	12
89	24-31	7	12	99	24-31	7	12
90	31-5	4	9	100	31-5	4	9

AND WEATHER DURING FIRST TEN DAYS AFTER EMERGENCE OF FEMALE

[illegible]

Items.	Max.	Min.	Ave.
--------	------	------	------

	0	358
Length of life of male adult in days	11	11
Length of life of female adult in days	4	11
Number of days from emergence to laying of first egg	2.5	9
Number of days from emergence to laying of last egg	1	6
Egg-laying period, in days	3.6	8
Number of eggs laid by one female	3.1	172
Average mean daily temperature	76.6	88.7
Average daily humidity	75.9	83
Average daily rainfall in inches	21.8	27.1

TABLE 15.—LIFE-HISTORY DATA ON PORTION OF SECOND GENERATION WHOSE LARVAE TRANSFORMED, ONEY, 1915.
LARVAE REARED IN APPLES ON TREE

Ser.	Eggs laid.	Larva hatched.	Larva left apple.	Larva pupated.	Adult emerged.	Length of life periods.						Total effective day-degrees.				
						Egg.	Larva in apple.	Larva in cocoon.	Total larval period.	Pupa.	Egg, larva, and pupa.	Egg (50+)— 2(88+).	Larva (50+)— 2(85+).	Pupa (50+)— 2(87+).	Egg, larva, and pupa.	Egg, larva, and pupa (50+)— 2(86+).
F.	July 2	July 11	July 31	Aug. 5	Aug. 19	9	20	5	25	11	43	161	628	231	1009	1009
M.	" 7	" 14	" 14	" 8	" 24	7	20	5	25	14	48	162	616	273	1099	1099
F.	" 7	" 13	" 9	" 13	" 27	7	24	3	27	14	51	182	750	257	1139	1140
F.	" 7	" 14	" 5	" 10	" 21	7	27	4	31	14	45	162	664	250	1041	1041
M.	" 7	" 14	" 5	" 10	" 23	7	22	5	27	13	47	162	664	273	1076	1076
M.	" 7	" 14	" 4	" 10	" 24	7	21	6	27	14	48	162	664	273	1099	1099
F.	" 7	" 14	" 9	" 13	" 27	7	26	4	30	14	51	162	721	257	1140	1140
M.	" 7	" 14	" 14	" 17	" 4	7	31	3	34	18	59	162	815	277	1254	1254
F.	" 8	" 14	" 2	" 3	Sept. 4	7	19	1	20	13	39	144	520	270	934	934
F.	" 8	" 14	" 9	" 16	Aug. 22	6	26	7	33	11	50	144	791	188	1039	1039
F.	" 8	" 14	" 13	" 17	" 27	6	30	4	34	16	56	144	815	238	1122	1122
F.	" 8	" 14	" 14	" 17	" 27	6	28	3	31	17	55	196	727	255	1197	1197
F.	" 10	" 17	" 14	" 17	Sept. 3	7									1178	1176

SUMMARY OF TABLE 15

Ser.	Egg.		Larva in fruit.		Larva in cocoon.		Larva.		Pupa.		Egg, larva, and pupa.			
	No.	Period in days.	No.	Period in days.	No.	Period in days.	No.	Period in days.	No.	Period in days.	Total effective day-degrees.		Period in days.	
											No.	Sum for stages.		(50+)— 2(86+)
M.	5	6.8	3	25.3	3	4.0	3	29.3	3	15.3	5	49	1106	1106
F.	8	6.5	8	24.8	8	4.1	8	29.0	8	13.6	8	49	1100	1099
Und.	1	9.0	1	20.0	1	5.0	1	25.0	0		0			
M.&F.	14	6.8	12	24.5	12	4.2	12	28.7	11	14.1	13	49	1102	1102

TABLE 17.—OVIPosition AND LAIE PERIOD OF ADULTS OF SECOND GENERATION, OLNBY, 1916,
AND WEATHER DURING FIRST TEN DAYS AFTER EMERGENCE OF MOTII

TABLE 17.—OVIPOSITION AND LIFE PERIOD OF ADULTS OF SECOND GENERATION, OLNEY, 1915,
AND WEATHER DURING FIRST TEN DAYS AFTER EMERGENCE OF MOTH

Emerged.		Died.		Days lived.		Number of eggs laid daily 1 to 8 days after emergence.								Av. mean daily temp.	Av. daily rainfall.	
Male.	Female.	Male.	Female.	Male.	Fe- male.	1	2	3	4	5	6	7	8	Total.		
Aug. 17	Aug. 16	Aug. 23	Aug. 25	6	9	.....	.....	.....	.....	.....	78	8	.....	86	66.7	.5375
" 21	" 20	" 30	Sept. 3	9	14	.....	.....	10	62	65	.....	6	.....	143	64.6	.347
" 23	" 23	" 30	Aug. 30	7	7	56	.....	9	.....	.....	.....	.....	.....	65	63.5	.0105
" 27	" 27	Sept. 2	Sept. 3	7	7	4	.....	5	.....	.....	.....	.....	.....	9	65.6	.008
" 27	" 27	" 3	8	6	12	.....	.....	.....	.....	.....	.....	.....	.....	.....	65.6	.008
" 27	" 27	" 8	12	7	16	.....	.....	.....	50	31	35	.....	23	139	65.6	.008
Sept. 5	Sept. 12	" 8	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Sept. 7	Sept. 2	" 8	8	6	6	.....	.....	.....	.....	.....	.....	.....	.....	.....	74.1	.038
" 9	" 7	" 15	15	.....	.....	.....	.....	.....	.....	32	26	.....	.....	58	78.0	.006
" 12	" 9	Sept. 14	14	5	5	.....	.....	30	.....	.....	.....	.....	.....	30	76.8	.036
" 12	" 12	" 15	25	3	13	.....	1	.....	.....	.....	.....	.....	.....	1	70.3	.072
Total					60	36	19	112	128	139	14	23	531			

* Killed Sept. 5, by larva of lacewing fly.

† Escaped.

SUMMARY OF TABLE 17

Items.	Max.	Min.	Av.
Length of life of male moth in days.....	9	3	6.1
Length of life of female moth in days.....	16	5	9.9
Number of days from emergence till egg-laying begins.....	7	2	3.7
Number of days from emergence till egg-laying ceases.....	9	3	5.4
Egg-laying period in days.....	5	1	2.6
Number of eggs laid by one female.....	143	1	66.3

TABLE 18—Oviposition and Late Period of Adults of Second Generation, Olney, 1916.
AND WEATHER DURING FIRST TEN DAYS AFTER EMERGENCE OF FEMALE

Male.	Emerg.	Died.	Adult period.	Number of eggs laid daily 1 to 12 days from date of emergence.												Total	Av. from daily temp.	Av. daily humid.	Av. daily temp.	Av. daily humid.
				1	2	3	4	5	6	7	8	9	10	11	12					
Aug. 16	Aug. 16	Aug. 20	Aug. 26	4	10	73										73	76.5	80	14.8	.245
" 22	" 21	Sept. 2	Sept. 6	9	9	64	28	16	12	5	5					92	68.0	79	13.2	.182
" 24	" 24	Sept. 24	Sept. 31	24	31	9										2	68.0	81	11.1	.195
" 25	" 25	" 25	" 25	5	5	14	12	7	12							92	68.3	81	11.1	.195
" 26	" 26	" 26	" 26	5	5	11	10	10	10							32	68.3	81	10.7	.195
" 27	" 27	Aug. 31	Aug. 31	4	4	9	10	10	10							15	69.1	81	10.7	.204
" 28	" 28	Sept. 5	Sept. 5	21	8	24	6	20	24							20	70.2	80	13.6	.151
" 29	" 29	" 29	" 29	5	5	7	20	56	20							82	72.5	83	12.3	.283
" 30	" 30	" 30	" 30	4	4	11	19		19							15	72.7	83	12.2	.283
" 31	" 31	" 31	" 31	5	5	54										64	72.5	83	11.8	.283
Sept. 5	Sept. 5	Sept. 11	Sept. 20	6	15											23	70.2	79	13.6	.142
" 6	" 6	" 15	" 14	8	8											57	67.4	78	13.5	.142
" 9	" 9	" 12	" 19	3	10											48	62.2	74	15.2	.000
" 11	" 11	" 21	" 21	11	11	37	1		6							37	61.0	71	17.5	.000
" 12	" 12	" 22	" 22	12	12											19	61.5	70	20.1	.000
Totals				5	5	8										805				

SUMMARY OF TABLE 18

Items.	Max.	Min.	Av.
Length of life of male moth.	12	3	6.13
Length of life of female moth.	24	3	11.09
Number of days from emergence to laying first egg.	8	1	4.1
Number of days from emergence to laying last egg.	12	1	5.2
EEG-laying period, in days.	10	1	2.2
Number of eggs laid by one female.	120	2	42.3
Average mean daily temperature.	72.7	60.4	68.7
Average daily humidity, in c.c.	83	70	79.0
Average daily rainfall, in inches.	20.1	0	17.4

F.	46	7.1	43	33.9	41	237.4	42	271.5	44	25.8	46	304.3	35	9.1	35	310.9
Und.	22	8.8	16	31.1	16	226.6	22	255.0	8	26.6	8	288.5	41	8.9	41	301.1
M&F.	111	7.4	101	33.0	98	233.6	105	265.7	94	26.2	97	300.8				

© 2004 Blackwell Publishing Ltd, *Journal of Internal Medicine* 255: 103–110

TABLE 20.—LIFE-HISTORY DATA ON HIBERNATING GENERATION, ONEY, 1916-17

Date	Egg laid	Larva hatched	Larva left apple	Larva dropped	Adult emerged	Egg.	Larva in apple.	Larva in cocoon.	Length of life periods.			Total life period.	Total day- age from Jan. 1 to date of pupation.
									Total larval period.	Pupa.	Egg, larva, and pupa.		
July 12	12	July 19	Aug. 19	Apr. 24	May 23	May 30	7	31	248	272	34	313	246
July 14	14	21	21	19	23	June 8	7	31	241	279	34	313	179
July 15	15	20	23	22	19	23	7	32	243	275	36	318	213
July 15	15	20	13	15	19	23	5	23	245	269	34	308	126
July 15	15	20	13	13	19	23	6	23				308	
July 15	15	21	13	11	19	23	6	23	241	265	39	309	
July 15	15	20	13	23	27	27	5	24	233	277	34	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27	27	5	24	233	277	35	316	
July 15	15	20	13	23	27								

1. The first part of the document is a letter from the President of the United States to the Congress, dated January 1, 1861. It contains a statement of the President's views on the secession of the Southern States and a declaration of his duty to maintain the Union.

2. The second part of the document is a report from the Secretary of the Treasury, dated January 1, 1861. It contains a statement of the Treasury's views on the financial condition of the United States and a declaration of its duty to maintain the Union.

3. The third part of the document is a report from the Secretary of the Interior, dated January 1, 1861. It contains a statement of the Interior's views on the land and mineral resources of the United States and a declaration of its duty to maintain the Union.

		1860	1861	1862	1863	1864	1865	1866	1867	1868	1869	1870	1871	1872	1873	1874	1875	1876	1877	1878	1879	1880	1881	1882	1883	1884	1885	1886	1887	1888	1889	1890	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099	2100	2101	2102	2103	2104	2105	2106	2107	2108	2109	2110	2111	2112	2113	2114	2115	2116	2117	2118	2119	2120	2121	2122	2123	2124	2125	2126	2127	2128	2129	2130	2131	2132	2133	2134	2135	2136	2137	2138	2139	2140	2141	2142	2143	2144	2145	2146	2147	2148	2149	2150	2151	2152	2153	2154	2155	2156	2157	2158	2159	2160	2161	2162	2163	2164	2165	2166	2167	2168	2169	2170	2171	2172	2173	2174	2175	2176	2177	2178	2179	2180	2181	2182	2183	2184	2185	2186	2187	2188	2189	2190	2191	2192	2193	2194	2195	2196	2197	2198	2199	2200	2201	2202	2203	2204	2205	2206	2207	2208	2209	2210	2211	2212	2213	2214	2215	2216	2217	2218	2219	2220	2221	2222	2223	2224	2225	2226	2227	2228	2229	2230	2231	2232	2233	2234	2235	2236	2237	2238	2239	2240	2241	2242	2243	2244	2245	2246	2247	2248	2249	2250	2251	2252	2253	2254	2255	2256	2257	2258	2259	2260	2261	2262	2263	2264	2265	2266	2267	2268	2269	2270	2271	2272	2273	2274	2275	2276	2277	2278	2279	2280	2281	2282	2283	2284	2285	2286	2287	2288	2289	2290	2291	2292	2293	2294	2295	2296	2297	2298	2299	2300	2301	2302	2303	2304	2305	2306	2307	2308	2309	2310	2311	2312	2313	2314	2315	2316	2317	2318	2319	2320	2321	2322	2323	2324	2325	2326	2327	2328	2329	2330	2331	2332	2333	2334	2335	2336	2337	2338	2339	2340	2341	2342	2343	2344	2345	2346	2347	2348	2349	2350	2351	2352	2353	2354	2355	2356	2357	2358	2359	2360	2361	2362	2363	2364	2365	2366	2367	2368	2369	2370	2371	2372	2373	2374	2375	2376	2377	2378	2379	2380	2381	2382	2383	2384	2385	2386	2387	2388	2389	2390	2391	2392	2393	2394	2395	2396	2397	2398	2399	2400	2401	2402	2403	2404	2405	2406	2407	2408	2409	2410	2411	2412	2413	2414	2415	2416	2417	2418	2419	2420	2421	2422	2423	2424	2425	2426	2427	2428	2429	2430	2431	2432	2433	2434	2435	2436	2437	2438	2439	2440	2441	2442	2443	2444	2445	2446	2447	2448	2449	2450	2451	2452	2453	2454	2455	2456	2457	2458	2459	2460	2461	2462	2463	2464	2465	2466	2467	2468	2469	2470	2471	2472	2473	2474	2475	2476	2477	2478	2479	2480	2481	2482	2483	2484	2485	2486	2487	2488	2489	2490	2491	2492	2493	2494	2495	2496	2497	2498	2499	2500	2501	2502	2503	2504	2505	2506	2507	2508	2509	2510	2511	2512	2513	2514	2515	2516	2517	2518	2519	2520	2521	2522	2523	2524	2525	2526	2527	2528	2529	2530	2531	2532	2533	2534	2535	2536	2537	2538	2539	2540	2541	2542	2543	2544	2545	2546	2547	2548	2549	2550	2551	2552	2553	2554	2555	2556	2557	2558	2559	2560	2561	2562	2563	2564	2565	2566	2567	2568	2569	2570	2571	2572	2573	2574	2575	2576	2577	2578	2579	2580	2581	2582	2583	2584	2585	2586	2587	2588	2589	2590	2591	2592	2593	2594	2595	2596	2597	2598	2599	2600	2601	2602	2603	2604	2605	2606	2607	2608	2609	2610	2611	2612	2613	2614	2615	2616	2617	2618	2619	2620	2621	2622	2623	2624	2625	2626	2627	2628	2629	2630	2631	2632	2633	2634	2635	2636	2637	2638	2639	2640	2641	2642	2643	2644	2645	2646	2647	2648	2649	2650	2651	2652	2653	2654	2655	2656	2657	2658	2659	2660	2661	2662	2663	2664	2665	2666	2667	2668	2669	2670	2671	2672	2673	2674	2675	2676	2677	2678	2679	2680	2681	2682	2683	2684	2685	2686	2687	2688	2689	2690	2691	2692	2693	2694	2695	2696	2697	2698	2699	2700	2701	2702	2703	2704	2705	2706	2707	2708	2709	2710	2711	2712	2713	2714	2715	2716	2717	2718	2719	2720	2721	2722	2723	2724	2725	2726	2727	2728	2729	2730	2731	2732	2733	2734	2735	2736	2737	2738	2739	2740	2741	2742	2743	2744	2745	2746	2747	2748	2749	2750	2751	2752	2753	2754	2755	2756	2757	2758	2759	2760	2761	2762	2763	2764	2765	2766	2767	2768	2769	2770	2771	2772	2773	2774	2775	2776	2777	2778	2779	2780	2781	2782	2783	2784	2785	2786	2787	2788	2789	2790	2791	2792	2793	2794	2795	2796	2797	2798	2799	2800	2801	2802	2803	2804	2805	2806	2807	2808	2809	2810	2811	2812	2813	2814	2815	2816	2817	2818	2819	2820	2821	2822	2823	2824	2825	2826	2827	2828	2829	2830	2831	2832	2833	2834	2835	2836	2837	2838	2839	2840	2841	2842	2843	2844	2845	2846	2847	2848	2849	2850	2851	2852	2853	2854	2855	2856	2857	2858	2859	2860	2861	2862	2863	2864	2865	2866	2867	2868	2869	2870	2871	2872	2873	2874	2875	2876	2877	2878	2879	2880	2881	2882	2883	2884	2885	2886	2887	2888	2889	2890	2891	2892	2893	2894	2895	2896	2897	2898	2899	2900	2901	2902	2903	2904	2905	2906	2907	2908	2909	2910	2911	2912	2913	2914	2915	2916	2917	2918	2919	2920	2921	2922	2923	2924	2925	2926	2927	2928	2929	2930	2931	2932	2933	2934	2935	2936	2937	2938	2939	2940	2941	2942	2943	2944	2945	2946	2947	2948	2949	2950	2951	2952	2953	2954	2955	2956	2957	2958	2959	2960	2961	2962	2963	2964	2965	2966	2967	2968	2969	2970	2971	2972	2973	2974	2975	2976	2977	2978	2979	2980	2981	2982	2983	2984	2985	2986	2987	2988	2989	2990	2991	2992	2993	2994	2995	2996	2997	2998	2999	3000	3001	3002	3003	3004	3005	3006	3007	3008	3009	3010	3011	3012	3013	3014	3015	3016	3017	3018	3019	3020	3021	3022	3023	3024	3025	3026	3027	3028	3029	3030	3031	3032	3033	3034	3035	3036	3037	3038	3039	3040	3041	3042	3043	3044	3045	3046	3047	3048	3049	3050	3051	3052	3053	3054	3055	3056	3057	3058	3059	3060	3061	3062	3063	3064	3065	3066	3067	3068	3069	3070	3071	3072	3073	3074	3075	3076	3077	3078	3079	3080	3081	3082	3083	3084	3085	3086	3087	3088	3089	3090	3091	3092	3093	3094	3095	3096	3097	3098	3099	3100	3101	3102	3103	3104	3105	3106	3107	3108	3109	3110	3111	3112	3113	3114	3115	3116	3117	3118	3119	3120	3121	3122	3123	3124	3125	3126	3127	3128	3129	3130	3131	3132	3133	3134	3135	3136	3137	3138	3139	3140	3141	3142	3143	3144</
--	--	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	--------

TABLE 21—OVIPOSITION AND LIFE PERIOD OF ADULTS OF THE HIBERNATING GENERATION, 1913,
WITH CLIMATIC DATA FOR FIRST TEN DAYS AFTER EMERGENCE OF FEMALE

[illegible]

Items.

SUMMARY OF TABLE 21

Length of life of male in days.	Length of life of female in days.	Number of days from emergence till laying of first eggs.	Egg-laying period in days.	Number of eggs laid by one female.
24	24	12	16	153
12.8	6	1	8	1
14.3	1	8	16	1
4.3	1	12	16	1
4.2	3	12	16	1
35.2	1	12	16	1

TABLE 22.—OVIPOSITION AND LIFE PERIOD OF HIBERNATING GENERATION, OLNEY, 1916, WITH CLIMATIC DATA FOR FIRST TEN DAYS AFTER EMERGENCE OF FEMALE

[illegible]

• Eggs laid June 5.

SUMMARY OF TABLE 22

Items.	Max.	Min.	Average
--------	------	------	---------

Length of life of male moth in days.

Length of life of female moth in days.

Number of days from emergence to laying

Number of days from emergence to laying
Egg-laying period, in days.

Number of eggs laid by one female.

Average mean daily temperature. Average daily humidity.

Average daily humidity.

Average daily evaporation in c. c.

..... inches, in length.

[illegible]

The following is a list of the
 names of the persons who have
 been appointed to the various
 positions in the office of the
 Secretary of the State of New York.
 The names are given in the order
 in which they were appointed.

STATE OF NEW YORK

1890		60	100	50	100	500	100	50
10	1	...	...	...	...	...	...	...
11	53	...	...	...	...	...	...	...
12	14	30	...	...	...	...	...	...
13	12	10	30	30	...	22	4	...
14	10	2	...	...	...	...	...	...
15	...	...	...	...	...	...	...	...
1	1000	0	...	...	...	...	...	...
2	1000	1	10	...	...	10	5	...
3	...	...	...	...	...	12	...	...
4	2	5	10	...	...	30	...	...
5	1000	10	...	...	...	...	...	...
6	1000	10	...	...	...	...	...	...
7	1000	10	...	...	...	...	...	...
8	1000	10	...	...	...	...	...	...
9	1000	10	...	...	...	...	...	...
10	1000	10	...	...	...	...	...	...
11	1000	10	...	...	...	...	...	...
12	1000	10	...	...	...	...	...	...
13	1000	10	...	...	...	...	...	...
14	1000	10	...	...	...	...	...	...
15	1000	10	...	...	...	...	...	...
16	1000	10	...	...	...	...	...	...
17	1000	10	...	...	...	...	...	...
18	1000	10	...	...	...	...	...	...
19	1000	10	...	...	...	...	...	...
20	1000	10	...	...	...	...	...	...
21	1000	10	...	...	...	...	...	...
22	1000	10	...	...	...	...	...	...
23	1000	10	...	...	...	...	...	...
24	1000	10	...	...	...	...	...	...
25	1000	10	...	...	...	...	...	...
26	1000	10	...	...	...	...	...	...
27	1000	10	...	...	...	...	...	...
28	1000	10	...	...	...	...	...	...
29	1000	10	...	...	...	...	...	...
30	1000	10	...	...	...	...	...	...
31	1000	10	...	...	...	...	...	...
32	1000	10	...	...	...	...	...	...
33	1000	10	...	...	...	...	...	...
34	1000	10	...	...	...	...	...	...
35	1000	10	...	...	...	...	...	...
36	1000	10	...	...	...	...	...	...
37	1000	10	...	...	...	...	...	...
38	1000	10	...	...	...	...	...	...
39	1000	10	...	...	...	...	...	...
40	1000	10	...	...	...	...	...	...
41	1000	10	...	...	...	...	...	...
42	1000	10	...	...	...	...	...	...
43	1000	10	...	...	...	...	...	...
44	1000	10	...	...	...	...	...	...
45	1000	10	...	...	...	...	...	...
46	1000	10	...	...	...	...	...	...
47	1000	10	...	...	...	...	...	...
48	1000	10	...	...	...	...	...	...
49	1000	10	...	...	...	...	...	...
50	1000	10	...	...	...	...	...	...
51	1000	10	...	...	...	...	...	...
52	1000	10	...	...	...	...	...	...
53	1000	10	...	...	...	...	...	...
54	1000	10	...	...	...	...	...	...
55	1000	10	...	...	...	...	...	...
56	1000	10	...	...	...	...	...	...
57	1000	10	...	...	...	...	...	...
58	1000	10	...	...	...	...	...	...
59	1000	10	...	...	...	...	...	...
60	1000	10	...	...	...	...	...	...
61	1000	10	...	...	...	...	...	...
62	1000	10	...	...	...	...	...	...
63	1000	10	...	...	...	...	...	...
64	1000	10	...	...	...	...	...	...
65	1000	10	...	...	...	...	...	...
66	1000	10	...	...	...	...	...	...
67	1000	10	...	...	...	...	...	...
68	1000	10	...	...	...	...	...	...
69	1000	10	...	...	...	...	...	...
70	1000	10	...	...	...	...	...	...
71	1000	10	...	...	...	...	...	...
72	1000	10	...	...	...	...	...	...
73	1000	10	...	...	...	...	...	...
74	1000	10	...	...	...	...	...	...
75	1000	10	...	...	...	...	...	...
76	1000	10	...	...	...	...	...	...
77	1000	10	...	...	...	...	...	...
78	1000	10	...	...	...	...	...	...
79	1000	10	...	...	...	...	...	...
80	1000	10	...	...	...	...	...	...
81	1000	10	...	...	...	...	...	...
82	1000	10	...	...	...	...	...	...
83	1000	10	...	...	...	...	...	...
84	1000	10	...	...	...	...	...	...
85	1000	10	...	...	...	...	...	...
86	1000	10	...	...	...	...	...	...
87	1000	10	...	...	...	...	...	...
88	1000	10	...	...	...	...	...	...
89	1000	10	...	...	...	...	...	...
90	1000	10	...	...	...	...	...	...
91	1000	10	...	...	...	...	...	...
92	1000	10	...	...	...	...	...	...
93	1000	10	...	...	...	...	...	...
94	1000	10	...	...	...	...	...	...
95	1000	10	...	...	...	...	...	...
96	1000	10	...	...	...	...	...	...
97	1000	10	...	...	...	...	...	...
98	1000	10	...	...	...	...	...	...
99	1000	10	...	...	...	...	...	...
100	1000	10	...	...	...	...	...	...

TABLE 23—OVIPOSITION AND LIFE PERIOD OF HIBERNATING GENERATION, OLNEY, 1917, AND CLIMATIC DATA FOR FIRST TEN DAYS AFTER EMERGENCE OF FEMALE

Moths emerged.		Moths died.		Adult period.		Number of eggs laid daily 1 to 16 days from date of emergence.																Av. mean daily temp.		Av. daily temp.		Av. daily temp.		Av. daily temp.																																																																																																																																																																																																																																																																																																																																																																																																																																												
Male.		Female.		Male.		Female.		Male.		Female.		Male.		Female.		Male.		Female.		Male.		Female.		Male.		Female.		Male.		Female.		Male.		Female.		Male.		Female.																																																																																																																																																																																																																																																																																																																																																																																																																																		
19		20		21		22		23		24		25		26		27		28		29		30		31		1		2		3		4		5		6		7		8		9		10		11		12		13		14		15		16		Total		Av. mean daily temp.		Av. daily temp.		Av. daily temp.		Av. daily temp.																																																																																																																																																																																																																																																																																																																																																																																																						
19	20	21	22	23	24	25	26	27	28	29	30	31	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total	Av. mean daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	Av. daily temp.	

Items.	Max.	Min.	Av.
--------	------	------	-----

	1952	1953
Length of life of male moth in days.	16	9.2
Length of life of female moth in days.	22	13.5
Number of days from emergence to laying of first eggs	10	4.8
Number of days from emergence to laying of last eggs	16	7.8
Egg-laying period in days.	12	4.0
Number of eggs laid by one female	156	42.4
Average daily humidity	68.5	61.4
Average daily evaporation, in cc.	78.5	72.3
Average daily rainfall, in inches	16.0	9.9
	528	17

199	2015	511	101	510	200
71	2012	51	101	50	100
100	2011	50	100	49	99
100	2010	49	99	48	98
100	2009	48	98	47	97
100	2008	47	97	46	96
100	2007	46	96	45	95
100	2006	45	95	44	94
100	2005	44	94	43	93
100	2004	43	93	42	92
100	2003	42	92	41	91
100	2002	41	91	40	90
100	2001	40	90	39	89
100	2000	39	89	38	88
100	1999	38	88	37	87
100	1998	37	87	36	86
100	1997	36	86	35	85
100	1996	35	85	34	84
100	1995	34	84	33	83
100	1994	33	83	32	82
100	1993	32	82	31	81
100	1992	31	81	30	80
100	1991	30	80	29	79
100	1990	29	79	28	78
100	1989	28	78	27	77
100	1988	27	77	26	76
100	1987	26	76	25	75
100	1986	25	75	24	74
100	1985	24	74	23	73
100	1984	23	73	22	72
100	1983	22	72	21	71
100	1982	21	71	20	70
100	1981	20	70	19	69
100	1980	19	69	18	68
100	1979	18	68	17	67
100	1978	17	67	16	66
100	1977	16	66	15	65
100	1976	15	65	14	64
100	1975	14	64	13	63
100	1974	13	63	12	62
100	1973	12	62	11	61
100	1972	11	61	10	60
100	1971	10	60	9	59
100	1970	9	59	8	58
100	1969	8	58	7	57
100	1968	7	57	6	56
100	1967	6	56	5	55
100	1966	5	55	4	54
100	1965	4	54	3	53
100	1964	3	53	2	52
100	1963	2	52	1	51
100	1962	1	51	0	50
100	1961	0	50	-1	49
100	1960	-1	49	-2	48
100	1959	-2	48	-3	47
100	1958	-3	47	-4	46
100	1957	-4	46	-5	45
100	1956	-5	45	-6	44
100	1955	-6	44	-7	43
100	1954	-7	43	-8	42
100	1953	-8	42	-9	41
100	1952	-9	41	-10	40
100	1951	-10	40	-11	39
100	1950	-11	39	-12	38
100	1949	-12	38	-13	37
100	1948	-13	37	-14	36
100	1947	-14	36	-15	35
100	1946	-15	35	-16	34
100	1945	-16	34	-17	33
100	1944	-17	33	-18	32
100	1943	-18	32	-19	31
100	1942	-19	31	-20	30
100	1941	-20	30	-21	29
100	1940	-21	29	-22	28
100	1939	-22	28	-23	27
100	1938	-23	27	-24	26
100	1937	-24	26	-25	25
100	1936	-25	25	-26	24
100	1935	-26	24	-27	23
100	1934	-27	23	-28	22
100	1933	-28	22	-29	21
100	1932	-29	21	-30	20
100	1931	-30	20	-31	19
100	1930	-31	19	-32	18
100	1929	-32	18	-33	17
100	1928	-33	17	-34	16
100	1927	-34	16	-35	15
100	1926	-35	15	-36	14
100	1925	-36	14	-37	13
100	1924	-37	13	-38	12
100	1923	-38	12	-39	11
100	1922	-39	11	-40	10
100	1921	-40	10	-41	9
100	1920	-41	9	-42	8
100	1919	-42	8	-43	7
100	1918	-43	7	-44	6
100	1917	-44	6	-45	5
100	1916	-45	5	-46	4
100	1915	-46	4	-47	3
100	1914	-47	3	-48	2
100	1913	-48	2	-49	1
100	1912	-49	1	-50	0
100	1911	-50	0	-51	-1
100	1910	-51	-1	-52	-2
100	1909	-52	-2	-53	-3
100	1908	-53	-3	-54	-4
100	1907	-54	-4	-55	-5
100	1906	-55	-5	-56	-6
100	1905	-56	-6	-57	-7
100	1904	-57	-7	-58	-8
100	1903	-58	-8	-59	-9
100	1902	-59	-9	-60	-10
100	1901	-60	-10	-61	-11
100	1900	-61	-11	-62	-12
100	1899	-62	-12	-63	-13
100	1898	-63	-13	-64	-14
100	1897	-64	-14	-65	-15
100	1896	-65	-15	-66	-16
100	1895	-66	-16	-67	-17
100	1894	-67	-17	-68	-18
100	1893	-68	-18	-69	-19
100	1892	-69	-19	-70	-20
100	1891	-70	-20	-71	-21
100	1890	-71	-21	-72	-22
100	1889	-72	-22	-73	-23
100	1888	-73	-23	-74	-24
100	1887	-74	-24	-75	-25
100	1886	-75	-25	-76	-26
100	1885	-76	-26	-77	-27
100	1884	-77	-27	-78	-28
100	1883	-78	-28	-79	-29
100	1882	-79	-29	-80	-30
100	1881	-80	-30	-81	-31
100	1880	-81	-31	-82	-32
100	1879	-82	-32	-83	-33
100	1878	-83	-33	-84	-34
100	1877	-84	-34	-85	-35
100	1876	-85	-35	-86	-36
100	1875	-86	-36	-87	-37
100	1874	-87	-37	-88	-38
100	1873	-88	-38	-89	-39
100	1872	-89	-39	-90	-40
100	1871	-90	-40	-91	-41
100	1870	-91	-41	-92	-42
100	1869	-92	-42	-93	-43
100	1868	-93	-43	-94	-44
100	1867	-94	-44	-95	-45
100	1866	-95	-45	-96	-46
100	1865	-96	-46	-97	-47
100	1864	-97	-47	-98	-48
100	1863	-98	-48	-99	-49
100	1862	-99	-49	-100	-50
100	1861	-100	-50	-101	-51
100	1860	-101	-51	-102	-52
100	1859	-102	-52	-103	-53
100	1858	-103	-53	-104	-54
100	1857	-104	-54	-105	-55
100	1856	-105	-55	-106	-56
100	1855	-106	-56	-107	-57
100	1854	-107	-57	-108	-58
100	1853	-108	-58	-109	-59
100	1852	-109	-59	-110	-60
100	1851	-110	-60	-111	-61
100	1850	-111	-61	-112	-62
100	1849	-112	-62	-113	-63
100	1848	-113	-63	-114	-64
100	1847	-114	-64	-115	-65
100	1846	-115	-65	-116	-66
100	1845	-116	-66	-117	-67
100	1844	-117	-67	-118	-68
100	1843	-118	-68	-119	-69
100	1842	-119	-69	-120	-70
100	1841	-120	-70	-121	-71
100	1840	-121	-71	-122	-72
100	1839	-122	-72	-123	-73
100	1838	-123	-73	-124	-74
100	1837	-124	-74	-125	-75
100	1836	-125	-75	-126	-76
100	1835	-126	-76	-127	-77
100	1834	-127	-77	-128	-78
100	1833	-128	-78	-129	-79
100	1832	-129	-79	-130	-80
100	1831	-130	-80	-131	-81
100	1830	-131	-81	-132	-82
100	1829	-132	-82	-133	-83
100	1828	-133	-83	-134	-84
100	1827	-134	-84	-135	-85
100	1826	-135	-85	-136	-86
100	1825	-136	-86	-137	-87
100	1824	-137	-87	-138	-88
100	1823	-138	-88	-139	-89
100	1822	-139	-89	-140	-90
100	1821	-140	-90	-141	-91
100	1820	-141	-91	-142	-92
100	1819	-142	-92	-143	-93
100	1818	-143	-93	-144	-94
100	1817	-144	-94	-145	-95
100	1816	-145	-95	-146	-96
100	1815	-146	-96	-147	-97
100	1814	-147	-97	-148	-98
100	1813	-148	-98	-149	-99
100	1812	-149	-99	-150	-100
100	1811	-150	-100	-151	-101
100	1810	-151	-101	-152	-102
100	1809	-152	-102	-153	-103
100	1808	-153	-103	-154	-104
100	1807	-154	-104	-155	-105
100	1806	-155	-105	-156	-106
100	1805	-156	-106	-157	-107
100	1804	-157	-107	-158	-108
100	1803	-158	-108	-159	-109
100	1802	-159	-109	-160	-110
100	1801	-160	-110	-161	-111
100	1800	-161	-111	-162	-112
100	1799	-162	-112	-163	-113
100	1798	-163	-113	-164	-114
100	1797	-164	-114	-165	-115
100	1796	-165	-115	-166	-116
100	1795	-166	-116	-167	-117
100	1794	-167	-117	-168	-118
100	1793	-168	-118	-169	-119
100	1792	-169	-119	-170	-120
100	1791	-170	-120	-171	-121
100	1790	-171	-121	-172	-122
100	1789	-172	-122	-173	-123
100	1788	-173	-123	-174	-124
100	1787	-174	-124	-175	-125
100	1786	-175	-125	-176	-126
100	1785	-176	-126	-177	-127
100	1784	-177	-127	-178	-128
100	1783	-178	-128	-179	-129
100	1782	-179	-129	-180	-130
100	1781	-180	-130	-181	-131
100	1780	-181	-131	-182	-132
100	1779	-182	-132	-183	-133
100	1778	-183	-133	-184	-134
100	1777	-184	-134	-185	-135
100	1776	-185	-135	-186	-136
100	1775	-186	-136	-18	

TABLE 24—SUMMARY OF LIFE-HISTORY DATA. LARVAE REARED IN APPLES OF TREE

Year.	Sex.	Eggs.		Larva in fruit.		Larva in cocoon.		Larva.		Pupa.		Eggs, larva, and pupa.		Adult.		Total life period.	
		No.	Period in days.	No.	Period in days.	No.	Period in days.	No.	Period in days.	No.	Period in days.	No.	Period in days.	No.	Period in days.	No.	Period in days.
		Total effective day-degrees (50+).		Sum for stages.		Sum for stages.		Sum for stages.		Sum for stages.		Sum for stages.		Sum for stages.		Sum for stages.	
1915	Male	28	9.6	16	28.3	16	4.3	28	31.9	28	10.7	28	51.9	1096	1184	1096	1184
	Female	46	9.7	36	28.9	31	4.4	44	34.6	46	10.6	46	54.3	1164	1164		
1916	Male and female	74	9.7	52	25.7	47	4.4	72	33.6	72	10.6	74	53.4	1122	1122		
	Male	31	7.8	30	31.0	30	3.6	32	35.1	32	9.8	31	52.1	1127	1127		
	Female	43	7.8	30	31.1	30	3.6	32	35.1	32	9.8	31	52.1	1127	1127		
1917	Male and female	104	9.3	99	25.7	95	4.5	97	30.1	97	10.9	104	50.3	1100	1111		
	Male	44	9.2	43	25.1	41	4.7	41	29.6	41	10.9	44	49.8	1104	1107		
	Female	61	9.3	48	26.1	46	4.4	46	30.6	47	10.9	61	50.5	1105	1116		
	Undetermined	9	9.8	8	26.4	8	4.3	8	30.6	9	11.0	9	51.6	1095	1105		
1916, 1917	Male and female	243	9.0	209	27.9	199	4.2	227	32.5	229	10.6	243	51.8	1118	1122	53	6.1
1916, 1917	Male	103	8.9	87	27.6	84	4.2	97	31.7	97	10.6	103	51.1	1104	1109	24	5.1
	Female	131	9.0	114	28.3	107	4.2	122	33.2	123	10.6	131	52.4	1128	1133	29	6.9
	Undetermined	9	9.8	8	26.4	8	4.5	8	30.6	9	11.0	9	51.6	1095	1105		
1915	Male and female	14	6.8	12	24.5	12	4.2	12	23.7	11	14.1	12	49.0	1102	1102		
	Male	36	5.8	33	21.6	32	4.2	33	26.0	33	11.8	36	42.0	1084	1099	25	9.7
	Female	54	6.0	51	22.9	51	4.3	51	27.2	51	12.0	54	44.9	1119	1123	38	10.2
	Undetermined	2	6.6	2	20.5	2	3.0	2	23.5	2	10.5	2	40.5	1071	1088		
1916	Male and female	92	6.0	86	22.3	85	4.2	86	26.4	86	11.9	92	44.1	1106	1118	63	10.0
	Male	41	5.9	36	21.9	35	4.2	36	27.3	36	12.1	41	43.7	1087	1100	35	9.7
	Female	62	6.1	59	23.1	59	4.3	59	26.4	59	12.2	62	45.4	1117	1129	38	10.2
	Undetermined	3	7.3	3	20.3	3	3.7	3	24.0	2	10.5	2	40.6	1071	1088		
1916	Male and female	106	6.0	98	22.6	97	4.2	98	26.8	97	12.1	106	44.7	1104	1119	63	10.0
	Male	43	7.1	42	32.7	41	4.1	41	23.3	42	26.5	43	29.9	1094	1109	6	7.5
	Female	46	7.1	43	33.9	41	4.2	41	27.2	44	25.8	46	30.4	1107	1121	35	9.1
	Undetermined	22	8.8	16	31.1	16	22.7	22	25.5	8	26.6	8	28.9				
1916-17	Male and female	111	7.4	101	23.0	98	23.4	105	26.6	94	26.2	111	30.1	1091	1106	41	8.9
	Male	57	6.1	56	26.4	54	23.6	55	26.2	52	25.0	54	30.3	1093	1107	18	8.7
	Female	66	5.9	62	26.2	54	24.0	56	26.6	52	25.0	61	30.6	1096	1110	25	12.5
	Undetermined	8	6.1	5	25.4	5	24.4	7	26.7	2	24.6	3	30.7				
1916-17	Male and female	131	6.0	123	20.2	113	23.8	118	26.4	106	34.3	118	30.5	1095	1111	43	11.1
	Male	100	6.5	98	29.1	95	23.5	96	26.4	94	31.2	97	30.1	1095	1111	24	8.4
	Female	112	6.4	103	29.4	95	23.1	98	26.9	96	30.8	107	29.4	1095	1111	60	10.6
1916-17 and 1916-17	Male and female	242	6.7	224	20.4	211	23.6	223	26.5	200	30.9	215	21.5	1095	1111	84	10.0
	Male	100	6.5	98	29.1	95	23.5	96	26.4	94	31.2	97	30.1	1095	1111	24	8.4
	Female	112	6.4	103	29.4	95	23.1	98	26.9	96	30.8	107	29.4	1095	1111	60	10.6
	Undetermined	30	8.1	21	23.7	21	23.1	29	25.8	10	28.2	11	29.4				

First generation.

Transforming part of second generation.

Inventing part of second generation and the third generation.

TABLE 25.—SUMMARY OF LIFE-HISTORY DATA. FIRST GENERATION LARVAE REARED IN PICKED APPLES

Year.	Sex.	Egg.		Larva in fruit.		Larva in cocoon.		Larva.		Pupa.		Egg, larva, and pupa.				Adult.		Total life period.	
		No.	Period in days.	No.	Period in days.	No.	Period in days.	No.	Period in days.	No.	Period in days.	No.	Period in days.	Sum of stages.	Total effective day-degrees.	No.	Period in days.		
1915	Male	14	8.0	7	24.9	7	3.7	14	27.2	14	10.6	14	45.9	1002	999				
	Female	17	7.8	9	22.4	9	3.6	17	27.1	17	10.8	17	45.7	1013	1012				
	Male and female	31	7.9	16	23.5	6	3.6	31	27.1	31	10.7	31	45.8	1008	1006				
1916	Male	37	9.7	32	21.2	32	4.6	33	26.0	33	10.1	37	46.0	1018	1018	30	5.3	30	51.6
	Female	50	9.4	50	20.4	49	4.6	49	24.8	49	10.0	50	44.4	1005	1006	44	6.2	44	50.5
	Male and female	87	9.5	82	20.7	81	4.6	82	25.3	82	10.1	87	45.1	1011	1011	74	5.9	74	50.9
1915 and 1916	Male	51	9.2	38	21.9	39	4.4	47	26.4	47	10.2	51	45.9	1014	1013	30	5.3	30	51.6
	Female	67	9.0	63	20.7	58	4.4	66	25.4	66	10.2	67	44.7	1007	1008	44	6.4	44	50.5
	Male and female	118	9.1	98	21.2	97	4.4	113	25.8	113	10.2	118	45.2	1010	1010	74	5.9	74	50.9

11. Taking 50 as the zero of development for all three stages and disregarding the slight differences in the units due to the use of 88, 85, and 87 as the degree of the maximum rate of development of the egg, larva, and pupa, respectively, we have for the equation of development of the three stages $PE = 1101$.

Since the larval period is about equal to the egg and pupal periods combined, the use of 86 degrees as the degree of maximum rate of development for all three stages will give about the same results and will give units of the same value for all three stages.

OBSERVATIONS ON THE LIFE HISTORY OF THE CODLING-MOTH IN 1915, 1916, AND 1917

Continuous observations were made on the life history of individuals throughout the seasons of 1915, 1916, and 1917. The methods employed in making these observations are described on page 228 of this article.

The following tables give the principal facts as to length of the periods, oviposition, and number of effective day-degrees which accumulated during the entire period of development. In computing the effective day-degrees for the stages, 50 degrees F. was taken as the zero of development and 88, 85, and 87 as the degree of maximum rate of development of the egg, larva, and pupa, respectively. By reason of the slightly different degrees of the maximum rate of development used for the different stages, the effective day-degrees of the different stages are units of not quite the same size and strictly speaking can not be added, but they differ so slightly that their sums, which are recorded in next to the last column in the tables, will serve as a basis for comparison.

In order that we might have a common unit in terms of which to express the accumulated effective day-degrees of the whole period from the deposition of the eggs to the emergence of the adult, it was necessary to use as the degree of the maximum rate of development a single point instead of 85, 87, and 88, and 86 was selected as the nearest integral degree to the weighted average of the three. Using 50 as the zero of development and 86 as the degree of maximum rate of development, the effective day-degrees which accumulated during the combined egg, larval, and pupal periods were computed and recorded in the last column in the tables. All of the tables bearing on the life history of the insect (Tables 9—25) follow.

Erratum: P. 253, last line, for "follow" read "*precede this page.*"

INCUBATION PERIOD

Eggs of the first generation hatch during May and June. The period varied from 13 days during the cooler period early in May to 5 days during the warmer parts of June, the average being 9 days for the 243 eggs used in the life history series. In a larger series of observations consisting of 2664 eggs the period varied from 15 days to 6 days and the average was 9.3 days.

Eggs of the second generation hatched during July, August, and the early part of September and the incubation period varied from 5 to 9 days, depending upon the temperature, the average for 106 eggs from which transforming larvæ hatched being 6 days. The eggs of the transforming larvæ hatch prior to the middle of August, during the warmest part of the season. Their incubation period is shorter than the period of those from which the hibernating larvæ hatch later in the season. The average period for 1748 second-generation eggs was 6.6 days.

Eggs of the third generation hatched during the latter half of August and during September. The period varied from 6 to 15 days, the average for 302 eggs observed being 8.2 days.

Eggs of the hibernating generation, which consists of a very small per cent. of the first generation, a larger per cent. of the second, and all of the third generation, hatched during July, August, and September. The incubation period varied from 5 to 15 days, the average for the 242 eggs used in the life-history series being 6.7 days.

There was practically no difference between the incubation period of male and of female eggs; the average period of 340 of the former belonging to all generations was 7.9 days and of 395 of the latter 7.8 days.

Early in May and late in September the incubation period is comparatively long, varying from 12 to 15 days. It decreases in length till midsummer, when it is only 5 days, and then increases in length till the end of the season. The relation of temperature to the length of the incubation period is shown in Table 1, page 235.

LARVAL PERIOD

Transforming larvæ.—The larval period of the first generation of larvæ reared in apples on the tree varied from a maximum of 42 days in the fruit and 9 days in the cocoon to a minimum of 18 days in the fruit and 1 day in the cocoon, the average period in the fruit being for males 27.6 days, for females 28.3 days, and for both males and females 27.9 days, and in the cocoon 4.2 days for both males and females.

The larval period of larvæ reared in picked apples averaged 21.2 days in the fruit and 4.4 days in the cocoon. The average total larval period of 227 first-generation larvæ reared in apples on the tree was 32.5 days and of 113 larvæ reared in picked fruit 25.8 days, the difference being 6.7 days. It was shown in Tables 3 and 4 that the accumula-

tion of effective day-degrees was 86 greater during the period of larvæ reared in apples on the tree than during the period of larvæ reared in picked fruit. Since the average daily accumulation of day-degrees shown in these tables is approximately 22.75, the difference in day-degrees represents a difference of about 4 days in the period. That is, larvæ of the first generation may be expected to mature, on an average, about 4 days earlier in picked fruit than in fruit on the tree. The difference of 6.7 days shown above is, therefore, partly due to differences in temperature as well as to difference in the condition of the fruit in which the larvæ fed.

The period of transforming larvæ of the second generation varied from a maximum of 33 days in the fruit and 7 days in the cocoon to a minimum of 17 days in the fruit and 1 day in the cocoon, the average period in the fruit being 22.6 days and in the cocoon 4.2 days. The average total period for 36 males was 26.3 and for 59 females 27.4, the average for both being 26.8 days. The larval period of the female was about one day longer than that of the male.

Hibernating larvæ.—In treating the larvæ of the hibernating generation no distinction has been made between larvæ of the different generations of the season which compose it. The period of the larvæ varied from a maximum of 46 days in the fruit and 269 days in the cocoon to a minimum of 16 days in the fruit and 209 days in the cocoon, the average period in the fruit being 29.0 days and in the cocoon 236. The average total period of hibernating larvæ was 264 for the males, 269 for the females and 265 for both males and females.

The length of the larval period is affected by temperature and the character of food. It also varies in length in different individuals, even when they are under the same conditions as to temperature and food. The individual variations are well illustrated by the following examples. The periods of 16 larvæ which hatched on May 31, 1917, varied from 25 to 33 days and the periods of 16 others which hatched June 11, 1917, varied from 24 to 38 days, though the environment of the individuals of each lot was as nearly the same as it was possible to have it. It is not infrequent that in lots of individuals kept under the same conditions as to light, food, heat, and moisture the variation in the period from the average for the group equals 30 per cent. of the average period.

The relation of temperatures to the length of the larval period is shown in Tables 3 and 4, pp. 240, 243. A comparison of these two tables also shows that development is more rapid in picked apples than in apples on the tree. According to Table 3, at an average mean daily temperature of 74.31° F., the average period is 29.07 days in apples on the tree; and according to Table 4, at an average mean daily temperature of 74.08° F., the period is 25.69 days in picked fruit, or 3.4 days less than the period in apples on the tree.

PUPAL PERIOD

Pupæ of the first generation were present from about the middle of June to the middle of August and the period varied from 8 to 14 days, the average being 10.6 days. Pupæ of the second generation were present during August and the first part of September. The period varied from 9 to 18 days, the average being 12.1 days. None of the third-generation larvæ pupated. The pupal period of this generation is therefore discussed in connection with the hibernating generation.

Pupæ of the hibernating generation were present during April, May, and the first part of June. The period varied from 39 days to 18 days, the average being 30.9 days. The average pupal period of the males and the females is practically the same. The period of the hibernating generation is much longer than that of the other generations because pupæ are present during early spring when the weather is cool.

COMBINED EGG, LARVAL, AND PUPAL PERIODS

The whole period of development is of the greatest importance since it is an index to the time which elapses from the deposition of the egg to the emergence of the adult. Since the deposition of eggs frequently begins within one day after the emergence of the female, the addition of one day to the period of development will give the time which elapses from the deposition of the egg of one generation to the deposition of the first egg of the following generation. For 103 males of the first generation the period varied from 40 to 59 days, the average being 51.1 days; for 131 females, the period varied from 43 to 62 days, the average being 52.4 days. For both males and females the average was 51.8 days.

The period of development for the individuals which hatch first in the spring is much longer than for those which hatch later, the minimum period for those hatching earliest being 50 days. We may expect, therefore, the deposition of the first eggs of the second generation to follow the deposition of the first eggs of the first generation in an average of about 51 days, though the average for this same period for the entire generation is only about 53 days. The above applies to individuals whose larval period was passed in apples on the tree. The period would be about 4 or 5 days shorter for those whose larvæ fed on picked apples.

The development period of 41 transforming males of the second generation varied from 38 to 50 days, the average being 43.7 days, and of 62 females from 33 to 56 days, the average being 45.4 days, the average for males and females being 44.7 days. The minimum period for the first individuals of the second generation was 37 days. We may, therefore, expect the deposition of eggs of the third generation to begin about 38 days after the deposition of the first eggs of the second generation.

The period from the first eggs of one generation to the first eggs of the next will vary with the season. The time which elapsed between

the deposition of the first eggs of the first and second generations was 59 days in 1915, in 1916 it was 53 days, and in 1917, 43 days. The time which elapsed between the deposition of the first eggs of the second and the first of the third generation in 1915 was 46 days, and in 1916, 39 days.

The total development period for 97 males of the hibernating generation varied from 266 to 318 days, the average being 301 days, and for 103 females from 271 to 324 days, the average being 305 days, and the average for both males and females being 303 days.

ADULT PERIOD

As shown in Tables 13 and 14,* 60 male adults of the first generation lived a maximum of 14 days, a minimum of 3 days, and an average of 6.4 days and 63 female adults a maximum of 15 days and an average of 7.4 days—an average of 6.9 days for both male and female adults. The averages given in Table 24 are for a smaller group and the averages are somewhat smaller.

Twenty-five male adults of the second generation lived a maximum of 12 days, a minimum of 3 days, and an average of 6.1 days; and 28 female adults lived a maximum of 24 days, a minimum of 5 days, and an average of 10.3 days (Tables 17, 18). The averages for a different and somewhat larger group shown in Table 24 are 9.7 days for the males, 10.2 days for the females, and 10 days for both males and females.

Ninety-one males of the hibernating generation, according to Tables 21, 22, and 23, lived a maximum of 24 days, a minimum of 3 days, and an average of 10.5 days, and 95 females lived a maximum of 27 days, a minimum of 5 days, and an average of 13.05 days. The averages of a smaller group, shown in Table 24, are smaller, being 10 days for both males and females.

TOTAL LIFE PERIOD

The total life period of 24 males of the first generation, the larvæ of which were reared in apples on the tree, varied from 40 days to 68 days, the average being 57.4 days; and that of 29 females varied from 43 days to 68 days, the average being 59.8, and the average for both males and females being 58.7.

The total life period of 30 males of the first generation, the larvæ of which were reared in picked apples, varied from 42 to 60 days, the average being 51.6 days, and that of 44 females varied from 42 to 58 days, the average being 50.5 days, and the average for both males and females being 50.9 days.

Of the second generation the total life period of 25 males whose larvæ transformed, varied from 42 to 61 days, the average being 51.3 days, and that of 38 females varied from 45 to 65 days, the average being 53.6 days.

* See group of tables following p. 253.

The remaining portions of the second generation and all of the third generation belong to the hibernating generation.

Of the hibernating generation, the total life period of 24 males varied from 286 days to 329 days, the average being 312 days, and that of 60 females varied from 288 to 330 days, the average being 314 days, and the average of both males and females being 313 days.

The maximum periods are for individuals whose larvæ left the fruit early in August, and the minimum periods for those whose larvæ left the fruit late in the fall. Larvæ which left the fruit late in the fall pupated and developed into moths at the same time as those which left the fruit earlier in the season as will be shown later on.

OVIPOSITION

Most of the first-generation females began to deposit eggs on the first or second day after emerging. The maximum number of eggs were laid on the second day. Oviposition ceased after the ninth day. The average number of eggs laid by each female was 39 in 1915 and 47.3 in 1916.

Oviposition by females of the second generation began later, but a majority of the moths had begun to oviposit by the third day. The maximum number of eggs in 1915 was laid on the sixth day and in 1916 on the second day after the emergence of the adults. This difference was no doubt due to the lower temperatures which prevailed in 1915. The average number of eggs laid by each female in 1915 was 66.3 and in 1916 it was 68.7.

Oviposition by females of the hibernating generation takes place in the spring when the weather is cool. Very few females begin to oviposit on the first day after emerging, and a majority do not begin to oviposit till the fourth day. The maximum number of eggs was laid on the fourth day after the emergence of the female in 1915 and 1916 and on the fifth day in 1917. Oviposition practically ceased after the tenth day but a few eggs were laid as late as the sixteenth day. The average number of eggs laid by each female varied from 30.5 in 1916 to 42.4 in 1917. Low temperatures and heavy precipitation delay oviposition.

Adults when confined in small cages do not act normally. They attempt to escape from the cage and soon become disabled. Doubtless in the open the females live longer and deposit a larger number of eggs than the averages above given. The maximum number of eggs laid by a single female was 172, the next highest numbers were 167, 156, 143, 136 and 120.

RELATION OF TEMPERATURE TO LENGTH OF DEVELOPMENT PERIOD

The total effective day-degrees which accumulated during the three development periods were determined in two ways: first, by adding together the total effective day-degrees of the egg, larval, and pupal periods

as determined by the use of 50 degrees F. as the zero of development and 88, 85, and 87 degrees F. as the degrees of the maximum rate of development of the egg, larva, and pupa respectively; and, second, by using 50 as the zero of development and 86 as the degree of the maximum rate of development for the entire period. The results are recorded in the next to the last and the last column, respectively, in the tables. The average total for the first generation, as shown in Table 24, computed by the latter method, was 1122, or 4 more than the total computed by the former method, and for the second generation it was 1119, or 15 more computed by the latter method than by the former method. The maximum difference amounts to less than half a day in the development period and hence the latter method may be used for practical purposes, and the following discussion will have reference to results obtained by it.

The average total day-degrees for the female is about 20 greater than for the male and 10 greater than the average for the male and the female, which indicates that the female has a slightly longer period than the male.

There is a large variation in individuals as to the length of the development period and hence in the total effective day-degrees which accumulate during the period. In individual cases these totals varied from 814 to 1475, but less than 4 per cent. of them were below 950, and less than 2 per cent above 1350. Since some of the extremely high and extremely low totals recorded were probably due to errors in observations, 950 and 1350 may be regarded as the approximate extremes, 1120 being the average.

The total day-degrees which accumulated during the development period of individuals whose larvæ were reared in picked fruit, as shown in Table 25, were 1010, or 109 less than the average for individuals whose larvæ were reared in apples on the tree, showing that larvæ develop more rapidly in picked fruit than in fruit on the tree.

SEASONAL HISTORY OF THE CODLING-MOTH, 1915*

The seasonal history of the codling-moth was determined at Olney by large-cage experiments, supplemented by data secured from band collections and the life history studies.

LARGE-CAGE SERIES

The cages (Fig. 5, 6, 7) used in these experiments were large enough to cover entire trees and were used for the purpose of keeping the generations under observation separate, so that the number of generations, the time of beginning, and the time of ending could be definitely determined. The events especially noted were dates when the first and the last moths

* A preliminary report on the observations and experiments of the year 1915 was published in the 29th report of the State Entomologist of Illinois, issued in January, 1916, and also in the annual report of the State Horticultural Society for 1915. That paper ("On the Life History of the Codling-moth," by Stephen A. Forbes and Pressley A. Glenn) contains some data and discussions not repeated in the present article.

were liberated in their respective cages, dates when the first and the last larvæ left the fruit, when they pupated, and when the moths emerged.

First generation, 1915.—The first moths which emerged from hibernating larvæ were liberated in cage No. 1, as follows:

	Date	Males	Females
May	1	4	1
"	2	2	0
"	3	8	4
"	4	0	1
"	5	4	2
"	6	12	6

The first eggs were found in the cage on the morning of May 6. They had probably been laid during the evening of the preceding day. These eggs hatched May 17. There was a heavy June drop of apples all over the orchard and the drop was especially heavy from some of the trees caged. In cage No. 1, 275 apples were picked up May 20 and placed in battery jars. They averaged only about one-half inch in diameter. June 4, 800 were picked up, June 9, 700, June 12, 300, and June 19, 150. At this time only a few apples remained on the tree. Larvæ began to leave the fruit in this cage June 22.

In another cage; in which moths had been liberated on May 12, or 12 days later than in cage No. 1, larvæ began to leave the fruit June 22. Judging from this, had normal conditions prevailed in cage No. 1, larvæ should have begun to leave the fruit 11 days earlier than they did—that is, on June 11. This date corresponds very well with the date when the first larvæ were taken under bands, which was June 12.

The last moths of the hibernating generation were liberated in cage No. 2, as follows:

	Date	Males	Females
May	31	11	9
June	1	4	5
"	2	3	4
"	3	5	8
"	8	6	12
"	9	2	3
"	10	1	1
"	11	1	3
"	12	2	3
"	13	1	4
"	15	1	1

Larvæ began to leave the fruit in cage No. 2 on July 6 and continued to leave the fruit till August 1. Pupation continued till August 4, and moths continued to emerge till August 17. Two larvæ which left the fruit July 17 and 19 respectively, hibernated. All other larvæ kept under observation transformed or died.

Second generation, 1915.—The first moths from cage No. 1 were liberated in cage No. 3, to rear the first of the second generation, as follows:

	Date	Males	Females
July	1	2	3
"	3	1	1
"	5	11	11
"	6	5	10

The first eggs were laid July 3, the first larvæ hatched July 11, the first larvæ left the fruit August 2 (these larvæ were lost), the first pupæ were found August 7, and the first moths emerged August 17.

The first larvæ to hibernate, left the fruit August 9. All larvæ which left the fruit after August 15, hibernated. The last pupa was obtained August 19 and the last moth September 2.

The last adults of the first generation to emerge from materials reared in cage No. 2 were liberated in cage No. 4, to rear the last of the second generation, as follows:

	Date	Males	Females
Aug.	2	4	2
"	3	6	3
"	4		3
"	5	5	8
"	6	4	4
"	7	2	
"	8	5	6
"	12	1	1
"	13	1	1
"	14	1	1
"	17		1
Sept.	6		1

The last eggs were laid September 12. The last of these eggs hatched September 17. Larvæ began to leave the fruit in this cage September 12 and continued to leave the fruit till November 1, the date of the last observation. All of the larvæ reared in this cage hibernated.

Third generation, 1915.—To rear the third generation, moths which were reared in cage No. 3 were liberated in cage No. 5, as follows:

	Date	Males	Females
Aug.	22	2	2
"	23	4	4
"	24	7	4
"	25	2	1
"	27	2	1
"	29	1	1
Sept.	3		2
"	5		1

The first eggs were observed August 26 and the first larvæ left the fruit September 28. The last egg observed was laid September 1 and hatched September 9. Since adults of the second generation continued

to emerge till September 5, oviposition no doubt continued till about September 15 and hatching till about September 25. Larvæ continued to leave the fruit till November 1, the date of the last observation. All the larvæ reared in cage No. 5 hibernated.

BAND COLLECTIONS

Hibernating generation, 1914-1915.—Hibernating larvæ were collected at Centralia and Olney April 12, 13, and 14. About 1400 were kept at Olney and the remaining 600 were kept under observation at Ozark. From 5 to 10 per cent. of the larvæ collected on the above dates had pupated. Judging from the time the first moths emerged, pupation began about April 9. Pupation was very irregular owing to variable weather conditions. It was at its maximum at Olney from April 22 to April 29, and continued till June 2. Larvæ kept under observation at Urbana, Illinois, 100 miles north of Olney, began to pupate April 20 and continued to pupate till May 24.

The first moths emerged at Olney April 27, the maximum emergence occurred May 14 and 15, and moths continued to emerge till June 26. A record of pupation and emergence of adults at Olney will be found in Table 26.

Collections made in 1915.—The bands used at Olney were two-ply burlap bands about 4 inches wide. They were placed on the trees about June 1 and examined daily until the first larvæ were found. After that they were examined every third day. When collected the number of males and females were recorded, and, at Olney, they were preserved for the purpose of observing pupation and emergence (Table 26).

Larvæ of the first generation began to leave the fruit June 12. The maximum number were leaving the fruit about June 25. The larvæ of the first and second generations overlapped during the last week in July and the first week in August. Development was greatly retarded during August on account of unusually cool weather, and was greatly accelerated during the second and third weeks of September on account of unusually warm weather. These weather influences are indicated in the band records by the relatively small number of larvæ collected during August and the large number during September. The falling off in band collections after September 21 was due largely to the fact that apple-picking began at about that date.

A daily record of the band collections, life-history observations, and climatic conditions at Olney in 1915 have been brought together in Table 26 for ready reference.

TABLE 28—SEASONAL HISTORY OF THE CODLING-MOTH AT OLNEY IN 1915

TABLE 26—DATA OBTAINED FROM BAND COLLECTIONS AND LIFE-HISTORY OBSERVATIONS.
WITH ACCOMPANYING CLIMATIC DATA, OLNEY, 1915

Date.	From hibernating larvae.		From larvae collected 1915.		Life history data.										Climatic data.				
	Pupæ.	Adults.	Larvæ under bands.	Pupæ.	Adults.	First generation.				Second generation.				Third generation.					
						Eggs.	Larvæ hatching.	Larvæ pupating.	Moths emerging.	Eggs laid.	Larvæ hatching.	Larvæ pupating.	Moths emerging.	Eggs.					Larvæ hatching.
Apr. 1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	34.5	16	53	11
" 2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	38.0	16	45	10
" 3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	38.0	8.5	72	9
" 4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	44.8	14.1	51	8
" 5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	66.8	12.1	69	7
" 6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	64.0	14.3	61	6
" 7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	62.0	16.7	80	5
" 8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	66.7	10.1	72	4
" 9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	60.0	5.1	53	3
" 10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	54.5	6	45	2
" 11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	45.3	1.6	72	1
" 12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	46.0	4.7	51	1
" 13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	50.3	5.8	69	1
" 14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	52.4	11.3	72	1
" 15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	60.8	10.0	51	1
" 16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	59.6	9.5	69	1
" 17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	58.2	14.2	61	1
" 18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	63.5	15.8	80	1
" 19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	65.7	14.1	72	1
" 20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	63.2	19.0	69	1
" 21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	64.1	21.4	59	1
" 22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	68.8	22.7	65	1
" 23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	72.7	22.4	59	1
" 24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	71.4	22.8	67	1
" 25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	72.3	22.8	54	1
" 26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	72.8	22.8	48	1
" 27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	72.8	22.8	48	1
" 28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	72.8	22.8	48	1
" 29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	72.8	22.8	48	1

TABLE 26—DATA OBTAINED FROM BAND COLLECTIONS AND LITERATURE ON CLIMATE, WITH ACCOMPANYING CLIMATE DATA, GILNEY, 1916

[illegible]

TABLE 28—SEASONAL HISTORY OF THE CODLING-MOTH AT OLNEY IN 1915

	Relative	Maximum	Relative	Latent
M&F.	5371	1421	1170	2780
	29.54	70.46	1104	2040

TABLE 27.—NUMBER OF LARVAE COLLECTED ON VARIOUS DATES IN 1915.
NUMBER TRANSFORMING AND NUMBER HIBERNATING.

Date of leaving applies.	Number of larvae collected.			Number discarded.	Number transforming.		Per cent transforming.		Number of adults emerging.	
	Total number.	Average number per day.	% sex.		1915.	1916.	1915.	1916.	1915.	1916.
June 11-16	18	5	M. F.	10 8	2	8	100.	100.	7	4
" 17-19	48	16	M. F.	26 22	2 1	6 25	100.	100.	21	21
" 20-22	96	32	M. F.	50 46	6 16	15 30	100.	100.	14	14
" 23-25	211	70	M. F.	77 134	16 14	63 100	100.	100.	41	41
" 26-28	189	63	M. F.	86 103	26 35	60 68	100.	100.	62	24
" 29-July 1	113	38	M. F.	46 67	6 15	40 52	100.	100.	50	66
July 2-3	101	51	M. F.	48 53	8 6	40 47	100.	100.	40	40
" 4-7	133	33	M. F.	57 76	5 15	49 39	94.2	95.1	47	49
" 8-10	66	22	M. F.	29 37	15 8	29 12	100.	100.	26	2
" 11-13	37	12	M. F.	19 18	7 6	12 20	100.	100.	11	11
" 14-16	46	15	M. F.	23 23	3 6	12 17	100.	100.	12	20
" 17-19	39	13	M. F.	18 21	3 11	10 10	100.	100.	12	12
" 20-22	40	13	M. F.	20 20	4 4	16 19	100.	100.	10	16
" 23-24	31	16	M. F.	14 17	1 4	14 13	100.	100.	14	14
" 25-28	40	10	M. F.	19 21	6 6	13 14	100.	93.3	13	13
" 29-31	19	6	M. F.	9 10	4 1	5 5	100.	100.	6.7	1
Aug. 1-3	21	7	M. F.	15 6	0 6	6 9	100.	100.	8	6
" 4-6	65	22	M. F.	33 32	4 17	9 26	92.9	93.8	4	22
" 7-9	100	33	M. F.	46 54	8 9	34 45	89.5	100.	11	4
" 10-12	82	27	M. F.	40 42	12 16	17 20	60.7	77.1	17	11
" 13-14	54	27	M. F.	26 28	7 12	13 13	77.1	88.4	20	6
" 15-18	145	36	M. F.	75 70	3 26	6 19	81.3	17.1	13	3
" 19-21	136	45	M. F.	74 62	34 10	7 3	81.9	29.4	6	31
" 22-24	174	58	M. F.	89 85	19 39	11 22	94.6	86.0	4	48
" 25-27	161	54	M. F.	75 86	8 18	2 0	95.6	97.	1	51
" 28-30	139	46	M. F.	71 68	25 22	0 0	100.	100.	2	22
" 31-Sept. 2	143	48	M. F.	69 74	18 10	0 0	100.	100.	0	30
Sept. 3-4	176	88	M. F.	83 93	18 34	0 0	100.	100.	0	28
" 5-8	434	109	M. F.	193 241	46 89	1 2	99.3	98.7	0	34
" 9-11	369	123	M. F.	148 221	31 66	2 0	100.	100.	1	127
" 12-14	733	131	M. F.	166 227	44 59	0 0	100.	100.	0	89
" 15-17	395	132	M. F.	176 219	53 88	0 0	100.	100.	0	107
" 18-20	232	77	M. F.	103 129	34 47	0 0	100.	100.	94	139
" 21-23	118	39	M. F.	61 57	7 6	0 0	100.	100.	62	61
" 24-25	111	37	M. F.	52 59	3 9	0 0	100.	100.	57	57
" 26-29	205	51	M. F.	103 102	17 17	0 0	100.	100.	40	40
" 30-Oct. 5	169	28	M. F.	89 80	5 5	0 0	100.	100.	35	60
Oct. 6-11	67	11	M. F.	37 30	1 1	0 0	100.	100.	0	64
" 12-18	128	18	M. F.	64 74	16 12	0 0	100.	100.	0	29
" 19-25	79	11	M. F.	33 16	9 11	0 0	100.	100.	0	25
" 26-Nov. 1	48	7	M. F.	28 20	2 0	0 0	100.	100.	0	63
Totals	5371		M. M.&F.	2480 5371	596 1421	648 1170	1386 2780	29.09 29.64	515 1104	1009 2040

TABLE 28—SEASONAL HISTORY OF THE CODLING-MOTH AT OLNEY IN 1915

Generation	Period	Earliest	Relatively numerous	Maximum	Relatively numerous	Latest
Hibernating	Pupæ	Apr. 9	Apr. 19	Apr. 26	May 4	June 2
	Adults	" 27	May 10	May 15	" 22	" 24
	Eggs	May 5	" 16		" 31	" 30*
First	Young larvæ	" 17	" 26		June 12	July 9†
	Mature larvæ	June 12	June 19	June 25	July 7	Aug. 9
	Pupæ	" 17	" 25	" 29	" 10	" 17
	Adults	" 28	July 10	July 12	" 22	Sept. 6
Second	Eggs	July 3	" 13		" 28	" 12
	Young larvæ	" 11	" 13		Aug. 3	" 17
	Mature larvæ	Aug. 2	Aug. 18	Sept. 17	" 20	—‡
	Pupæ	" 3		Aug. 10		Aug. 18§
	Adults	" 16				Sept. 5§
Third	Eggs	" 22				" 13
	Young larvæ	" 29				" 19
	Mature larvæ	Sept. 22				—†

* The last eggs observed were laid June 26.

† The latest hatching-date record is June 27, the eggs having been laid June 18.

‡ Larvæ were collected Nov. 1, the date of the last observation.

§ These dates are from materials collected from cages, but larvæ from the much larger band-collections continued to pupate till Aug. 30, and moths to emerge till Sept. 16. No doubt egg-laying continued till about Sept. 26 and hatching of larvæ till about Oct. 7.

Data based on the band collections give in a general way the distribution as to relative numbers of individuals of each stage throughout the season; the life history data indicate only approximately the general periods during which the different stages of each generation occurred. Since only a small number of individuals were used in the life-history observations as compared with the number of individuals in the whole orchard, activities in the orchard, no doubt, began somewhat earlier and continued somewhat later than the life history data indicate. This is especially true in regard to the date of the deposition of the last eggs, the hatching of the last larvæ, etc., of each generation, because usually the last individuals were very few in number and were mostly females, many of which died without oviposition or laid infertile eggs.

Hibernation, 1915.—The first larvæ to hibernate left the fruit between July 3 and July 7. There was a period of three cool days, including July 4, 5, and 6, when the mean daily temperatures were 65.2, 61.1 and 65.5 degrees F. respectively. For the remainder of July the temperature was much higher. The cool days no doubt account for the early hibernation of some of the larvæ which left the fruit from July 3 to July 7. Hibernation proper began with larvæ which left the fruit between August 3 and August 6, after which the per cent. that hibernated increased rapidly until August 20. Practically all larvæ maturing after this date hibernated. The weather during the second week in September was unusually warm and it was expected that larvæ would again begin to transform, but only three out of about 1000 which were under observation responded to this increased temperature.

Of the total number of larvæ collected, 46.2 per cent. were males and 53.8 per cent. were females; 29.1 per cent. of the males and 30.1 per cent. of the females collected, transformed; and 70.9 per cent. of the males and 69.9 per cent. of the females hibernated.

SUMMARY OF THE SEASONAL HISTORY, 1915

From the foregoing data the seasonal history of the codling-moth at Olney in 1915 may be constructed quite accurately (Table 28, preceding this page).

In Chart 1, these same details of the seasonal history are shown. An attempt is made here to show in graphic form the relative numbers of pupæ, adults, eggs, young larvæ, and mature larvæ that appeared from day to day, all of which have been averaged for three-day periods. The chart is divided vertically into columns for the months from April to October and longitudinally by lines representing elevations above certain base lines, the degree of elevation being represented by the figures in the column to the left of the chart. The average numbers of pupæ, adults, eggs, young larvæ and mature larvæ which appeared daily during each of the three-day periods are represented by the black vertical columns. At the top of the chart the three broods of pupæ are represented, next comes the three broods of moths, then the eggs, then young larvæ, and lastly, the larvæ leaving the fruit. The three broods are indicated very distinctly in the parts of the chart representing different stages. In the lower part of the chart the mean daily temperatures above 50° are represented, also averaged for three-day periods.

RECORDS FOR OTHER POINTS THAN OLNEY

Thus far the discussion has been confined almost entirely to the Olney records. A few words additional will suffice for the less complete records at Ozark, Plainview, and Princeton. The codling-moth was so scarce at the last-mentioned place as to render the records of little value. A distinct third generation was detected at Ozark the same as at Olney. Since only band records were kept at Plainview no evidence of the third generation was noticed there, though it doubtless occurred and would have been detected if a daily, or even a weekly, record of the emergence of moths from the larvæ collected under bands had been kept.

The first moths observed at Ozark emerged April 28, or one day later than at Olney. The first larvæ of the first generation were taken under bands at Ozark June 2, at Olney June 12, and at Plainview June 25. The first of the second-brood moths emerged at Ozark June 20, or 8 days before the first moths of this brood emerged at Olney, and the first of the second-brood larvæ hatched at Ozark July 2, or 9 days before they hatched at Olney.

GENERAL REMARKS ON THE SEASON

March and April, 1915, were dry months and much warmer than normal, causing the pupation of the hibernating larvæ to begin early, but during May, June, July, and August the temperature averaged from 4 to 7.5 degrees cooler than normal, and the rainfall for these months was much above normal. These months were characterized by many cool, cloudy, rainy days, all of which tended to retard the development of the codling-moth, and to reduce the numbers of each generation that survived. This threw the beginning of the pupation of the first third-brood pupæ as late as August 7, which was only two weeks before pupation ended for the season. For this reason the third generation was very small.



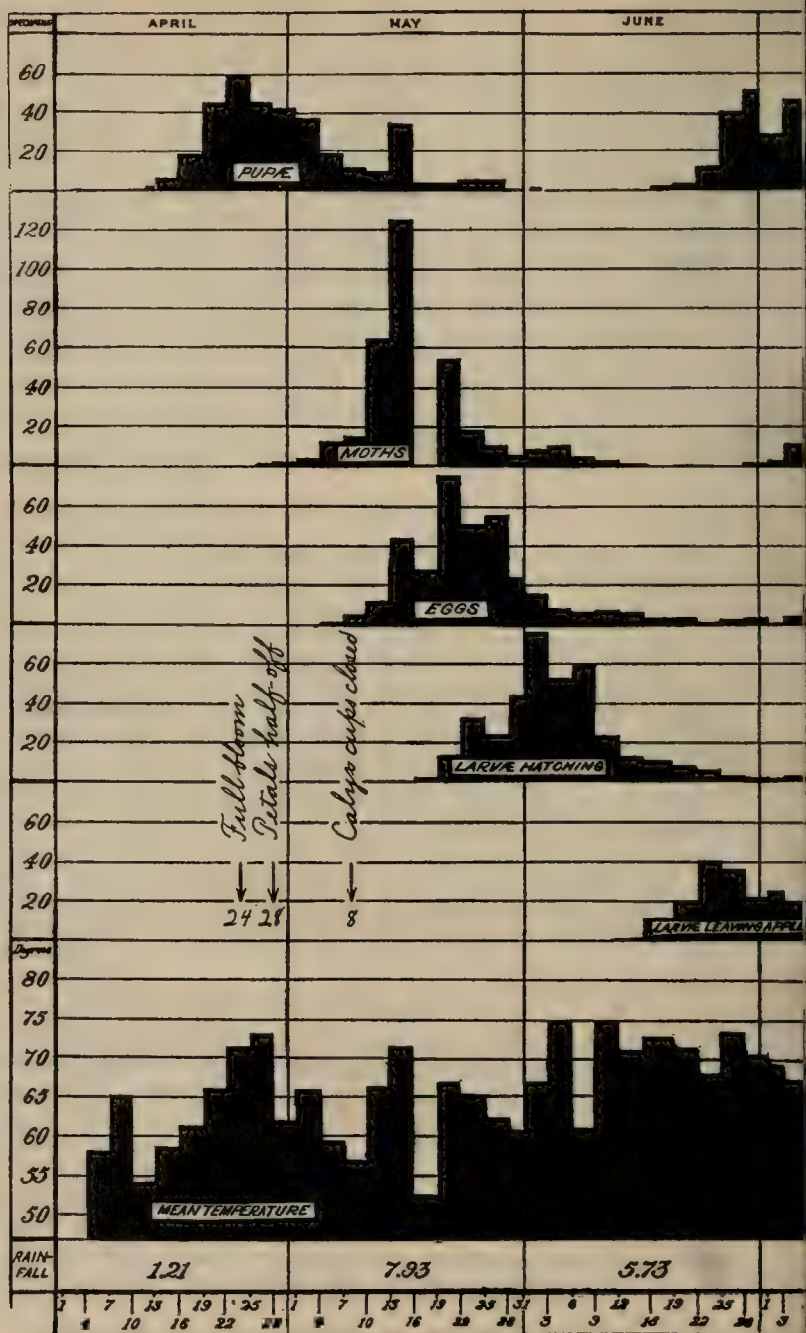
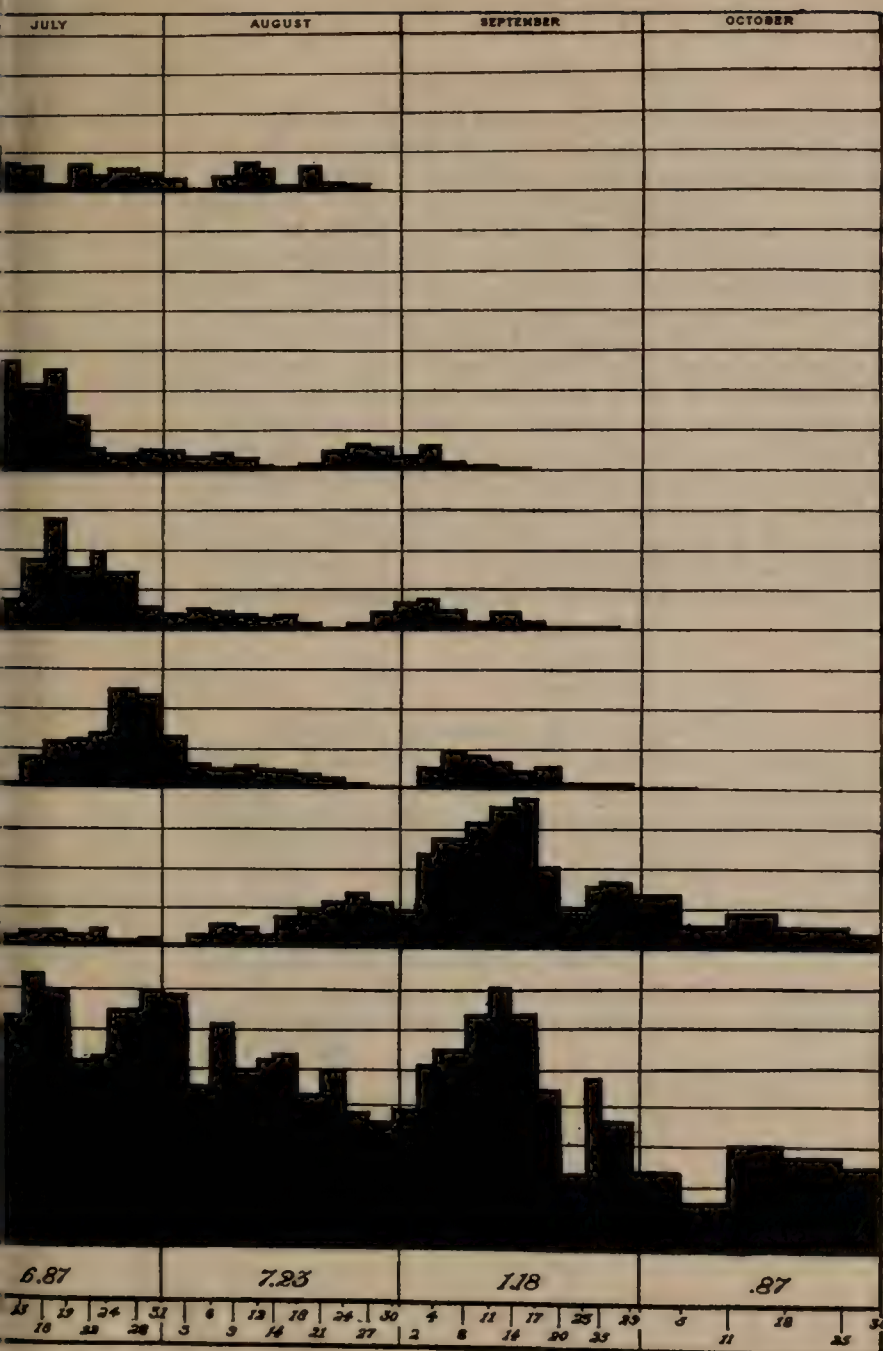


Chart 1. Seasonal history





SEASONAL HISTORY OF THE CODLING-MOTH, 1916

The plan of work pursued in the 1915 studies was continued in 1916. An effort was made to make the records at Ozark and Plainview a little more complete, and another station was established at Springfield. The observations at Princeton were discontinued.

The spring months were cold and the season backward. April was about 3 degrees below normal and about 9 degrees below what it was in 1915. The temperature for May was about normal, for June about 5 degrees below normal, July and August one degree above normal. Rain was fairly well distributed throughout the season. The pupation of the hibernating larvæ began rather late. Development was normal during May, slower than normal during June, and proceeded at the maximum rate throughout July and August. On the whole, development was not quite so rapid as it would be in a normal year, the total accumulation of monthly degrees above 50 degrees, based upon mean monthly temperatures for April, May, June, July, and August, having been 89 while the normal accumulation for the same period is 93.3. As compared with 1915 the year 1916 was more favorable for development, the accumulation of monthly temperatures above 50 degrees from April to August inclusive in 1915 having been only 85.5.

LARGE-CAGE SERIES

Hibernating generation, 1915-1916.—The hibernating larvæ began to pupate April 16 and continued to pupate till June 2. Moths began to emerge May 10 and continued to emerge till June 23.

First generation.—The first eggs observed were laid May 14. These eggs hatched May 25. It was not necessary to use a large cage in order to secure the first pupæ and adults of the first generation, since they could be obtained from the first larvæ collected from the bands. Larvæ of this generation began to leave the fruit June 20, to pupate June 24, and moths began to emerge July 3.

To secure the last individuals of the first generation, the last adults which emerged from the hibernating material were liberated in cage No. 1, as follows:

Date	Males	Females
June 1	12	0
" 3	9	8
" 6	1	3
" 8	6	3
" 10	5	4
" 12	11	11
" 13	1	3
" 15		1
" 17		2
" 20		3
" 23		6

Larvæ began to mature and leave the fruit July 11 and continued to leave the fruit till August 9. The last pupation occurred August 14, and the last emergence on August 20. All the larvæ of this generation transformed.

Second generation.—For the purpose of getting the earliest individuals of the second generation, the first moths of the first generation were liberated in large-cage No. 2, as follows:

Date	Males	Females
July 6	3	3
" 7	1	1
" 8	1	3
" 9	2	1
" 10	3	2
" 12	5	7
" 14	13	8
" 16	2	12

July 20, many apples in the cage were showing signs of worminess. Larvæ began to leave the fruit August 3, to pupate August 7, and moths began to emerge August 16.

To rear the last individuals of the second generation, moths which emerged from cage No. 1 on or after August 10 were liberated in cage No. 3 as follows:

Date	Males	Females
Aug. 10	4	4
" 11	8	3
" 12	4	3
" 13	1	1
" 15	1	1
" 17	1	
" 18	2	
" 20		1

Larvæ began to leave the fruit September 20 and continued to leave it until observations closed, October 12. All the larvæ reared in this cage hibernated.

Third generation.—To rear the third generation, moths which emerged from cage No. 2 were liberated in cage No. 4 as follows:

Date	Males	Females
Aug. 16	1	1
" 18	2	
" 20	1	1
" 23	5	1
" 24	1	3
" 25		4
" 26		1
" 27		2
" 30	1	1
Sept. 2	1	2
" 8	2	1

The adults liberated September 8 were from the second generation of the life-history series.

TABLE 29.—RELATION OF TIME OF LEAVING THE FRUIT TO TIME OF EMERGENCE OF MOTHS OF THE HIBERNATING GENERATION OF 1915-16, OLNEY, 1916

Dates of emergence and number emerging.

The first eggs were observed August 19. These hatched August 23. The first mature larvæ left the fruit between September 26 and October 3, and larvæ continued to leave the fruit till October 23—the date of the last observation.

Thus the presence of a partial third brood was again demonstrated this year at Olney. Larvæ of the first generation were entering the fruit from May 25 to about July 4, and larvæ of the second generation from about July 13 to September 1, and larvæ of the third generation from August 23 to about September 15.

BAND COLLECTIONS

Hibernating generation, 1915–1916.—Pupation of the hibernating larvæ collected from bands in 1915 began at Ozark April 10, at Olney, Plainview, and Springfield April 13, and closed at Ozark May 31, at Olney June 17, and at Springfield May 26.

Moths began to emerge at Ozark and at Olney May 11 and at Springfield May 10. They continued to emerge at Ozark till June 19, at Olney till June 30 (Table 29, foot-note), and at Springfield till June 28. Pupation was very irregular on account of changes in the weather conditions.

The dates when the larvæ left the fruit had no appreciable influence on the time of pupation and emergence the following spring. The average date of the emergence of males was May 21, and of the females May 23. We should naturally expect that hibernating larvæ maturing in July would develop into moths earlier in the spring than those maturing later in the season, but this is not the case. The male moths in three collections emerged an average of from one to five days later than the females; in two collections the average dates of emergence of both sexes were the same; and in the other eighteen collections the males emerged an average of from one to seven days earlier than the females. For the whole series the average date of emergence of the males was 2.6 days earlier than that of the females.

Collections made in 1916.—Band collections were made at Ozark, Olney, and Springfield. The results are shown in Table 30.

The first eggs were observed August 19. These hatched August 23.

While the first moths of the hibernating generation observed at the three places emerged at about the same time, the first larvæ of the first generation matured 10 days later at Olney than at Ozark and 9 days later at Springfield than at Olney. The first pupæ were observed at Olney June 24, and at Springfield July 2; the first adult at Olney emerged July 3, and at Springfield July 11 (Table 31). The second and third broods of pupæ and moths are very clearly indicated in these pupation and emergence records. The pupation of the second brood at Olney began June 24 and continued till the first or second week in August, at which time the beginning of the pupation of the third brood is indicated by the increase in the number of pupæ. The second brood of moths began to emerge July 3 and continued to emerge until about the second

week in August. The beginning of the emergence of the third brood is indicated by the increase in the number of moths emerging daily after the 16th of August. Judging from the above data the third brood was about equal in number to the second brood.

TABLE 30—RECORD OF LARVAE COLLECTED UNDER BANDS AT OZARK, OLNEY, AND SPRINGFIELD IN 1916

Date	Ozark	Olney	Spring- field	Date	Ozark	Olney	Spring- field
June 10	11	.....	.....	Aug. 16	24	344	28
12	7	.....	.....	19	16	315	
14	6	.....	.....	22	31	350	42
17	8	.....	.....	25	22	490	44
20	15	7	.....	28	30	412	46
23	50	11	.....	31	37	516	
26	31	29	.....	Sept. 2	43	354	45
29	53	47	5	6	24	797	55
July 1	56	65	27	9	28	515	91
5	45	213	20	12	45	551	79
8	55	228	17	15	37	566	
11	48	225	32	18	22	399	
14	30	110	33	21	15	388	
17	56	121	33	23	31	276	
20	73	138	30	25	28	217	132
24	36	76	41	28	21		
26	22	197	22	Oct. 3	37	136	
29	28	72	15	6	8		
Aug. 1	61	43	.....	10	8	142	
4	52	70	36	13	5		
7	40	125	59	16	5		
10	53	221	67	19	1		
12	53	230	86	24		92	
				Totals	1407	9086	1085

Hibernation, 1916.—Table 32 shows the dates between which the transition was made from transforming to hibernating larvæ.

Hibernation began with larvæ which left the fruit between August 4 and August 7, but hibernation in considerable numbers began with larvæ collected between August 16 and August 19. Practically all larvæ collected after August 28 hibernated. This was fully a week later than the date on which active hibernation began in 1915. It will be seen, then, that a large per cent. of the larvæ which left the fruit during the first three weeks in August transformed; it will also be seen by referring to Table 30 that larvæ of the second generation were leaving the fruit in large numbers during this period. This accounts for the relatively large size of the third generation in 1916.

Of the 9088 larvæ collected at Olney, 4100, or about 45 per cent., were males, and 4988, or about 55 per cent., were females.

TABLE 31.—RECORD SHOWING THE NUMBER OF LARVAE PUPATING AND MOTHS EMERGING DAILY AT OINEY AND SPRINGFIELD FROM BAND COLLECTIONS IN 1916

Date.	No. of larvae pupating.		No. of moths emerging.	
	Oiney.	Springfield.	Oiney.	Springfield.
June 20				
" 21				
" 22				
" 23	2		1	
" 24	5		1	
" 25	2		4	
" 26	5		5	
" 27	6		3	
" 28	3		4	
" 29	6		3	
" 30	2		5	
July 1	9		5	
" 2	11	4	7	
" 3	42	5	14	
" 4	22	2	23	
" 5	7		10	
" 6	15	4	9	
" 7	19	1	6	
" 8	46	7	7	
" 9	40	2	14	
" 10	47	6	10	
" 11	54	8	9	
" 12	44	2	14	
" 13	32	4	23	
" 14	82	2	6	
" 15	63	4	22	
" 16	17		6	
" 17	62		11	
" 18	26		34	
" 19	26		23	
" 20	36		34	
" 21	36		37	
" 22	15		32	
" 23	26		31	
" 24	19		39	
" 25	39		37	37
" 26	50		47	14
" 27	35		34	7
" 28	26		33	3
" 29	38		25	6
" 30	32		37	7
" 31	30		20	9
Aug. 1	23		14	8
" 2	11		26	14
" 3	18		24	8
" 4	6		29	
" 5	17		10	23
" 6	23		33	
" 7	16		29	15
" 8	8		28	5
" 9	46		17	13
" 10	28		11	2
" 11	5		7	2
" 12	46		8	1
" 13	39		4	3
" 14	27		16	
" 15	79		20	12
" 16	92		19	7
" 17	38		16	9
" 18	39		23	1
" 19	37		17	21
" 20	21		14	10
" 21	9		15	8
" 22	21		17	22
" 23	14		21	
" 24	31		10	9
" 25	8		9	8
" 26	4		10	3
" 27	6		9	6
" 28	4		15	9
" 29	13		19	6
" 30	7		34	9
" 31	8		24	24
Sept. 1	11		29	1
" 2	3		10	1
" 3	1		29	1
" 4			10	1
" 5			17	1
" 6			27	1
" 7	1		21	1
" 8			11	1
" 9			8	
" 10			11	
" 11			13	
" 12			13	
" 13			3	
" 14				
" 15				
" 16				
" 17				
" 18				
" 19				
" 20				
" 21				
" 22				
" 23				
" 24				
" 25				
" 26				
" 27				
" 28				
" 29				
" 30				
" 31				

s
d
t.
st
l,
or
is
n
d

id
le

al
he

he
nd

ac-
nd
he
ng
are
for

m-

ng

ng

ng

TABLE 32.—NUMBER OF LARVAE COLLECTED ON VARIOUS DATES IN 1916,
NUMBER TRANSFORMING AND NUMBER HIBERNATING

Dates of leaving apples.	Number of larvae collected.		Sex.	Numbers of each sex.	Number dis- carded.	Number transforming.		Percent transforming.		Number of adults emerging.	
	Total number.	Average number per day.				1916.	1917.	1916.	1917.	1916.	1917.
June 15-20	7	1.4	M. F.	5 2	.....	5	.....	100.	.....	4	.....
" 21-23	11	4	M. F.	3 8	.....	3	.....	100.	.....	2	.....
" 24-26	29	10	M. F.	16 13	.....	8	.....	100.	.....	3	.....
" 27-29	47	16	M. F.	13 28	.....	12	.....	100.	.....	7	.....
" 30-July 1	65	38	M. F.	19 32	.....	11	.....	100.	.....	8	.....
July 2-5	213	53	M. F.	7 33	.....	17	.....	100.	.....	6	.....
" 6-8	228	76	M. F.	31 108	.....	22	.....	100.	.....	12	.....
" 9-11	225	75	M. F.	28 105	.....	25	.....	100.	.....	18	.....
" 12-14	110	37	M. F.	6 104	.....	29	.....	100.	.....	19	.....
" 15-17	121	40	M. F.	33 106	.....	25	.....	100.	.....	21	.....
" 18-20	138	49	M. F.	18 122	.....	77	.....	100.	.....	63	.....
" 21-22	76	38	M. F.	98 127	.....	72	.....	100.	.....	48	.....
" 23-26	197	49	M. F.	127 164	.....	78	.....	100.	.....	59	.....
" 27-29	72	24	M. F.	18 127	.....	80	.....	100.	.....	65	.....
" 30-Aug. 1	43	14	M. F.	64 104	.....	102	.....	100.	.....	79	.....
Aug. 2-4	70	23	M. F.	27 16	.....	55	.....	100.	.....	34	.....
" 5-7	125	42	M. F.	16 32	.....	46	.....	100.	.....	35	.....
" 8-10	221	70	M. F.	61 108	.....	48	.....	100.	.....	33	.....
" 11-12	230	115	M. F.	64 113	.....	49	.....	100.	.....	35	.....
" 13-16	344	88	M. F.	68 100	.....	51	.....	100.	.....	43	.....
" 17-19	315	105	M. F.	70 162	.....	54	.....	100.	.....	37	.....
" 20-22	350	117	M. F.	35 182	.....	55	.....	100.	.....	35	.....
" 23-25	490	163	M. F.	41 193	.....	58	.....	100.	.....	20	.....
" 26-28	412	104	M. F.	33 104	.....	70	.....	100.	.....	47	.....
" 29-31	516	172	M. F.	33 104	.....	70	.....	100.	.....	50	.....
Sept. 1-6	354	177	M. F.	27 16	.....	26	.....	100.	.....	24	.....
" 7-9	515	172	M. F.	27 16	.....	26	.....	100.	.....	26	.....
" 10-12	551	184	M. F.	13 28	.....	26	.....	100.	.....	13	.....
" 13-15	566	189	M. F.	13 28	.....	26	.....	100.	.....	16	.....
" 16-18	339	133	M. F.	13 28	.....	26	.....	100.	.....	13	.....
" 19-21	388	129	M. F.	13 28	.....	26	.....	100.	.....	12	.....
" 22-23	276	138	M. F.	13 28	.....	26	.....	100.	.....	12	.....
" 24-25	217	109	M. F.	13 28	.....	26	.....	100.	.....	12	.....
" 26-Oct. 2	136	19	M. F.	13 28	.....	26	.....	100.	.....	12	.....
Oct. 3-10	142	12	M. F.	13 28	.....	26	.....	100.	.....	12	.....
" 11-24	92	7	M. F.	13 28	.....	26	.....	100.	.....	12	.....
Totals	9088	.....	M. F.	1681 2277	.....	959 1915	.....	39.6 37.3	60.4 62.7	783 1510	.....
			M. F.	4988 3958	.....	956 3215	.....	35.3 37.8	64.7	727 1510	.....
			M. F.	1681 2277	.....	959 1915	.....	39.6 37.3	60.4 62.7	783 1510	.....
			M. F.	4988 3958	.....	956 3215	.....	35.3 37.8	64.7	727 1510	.....
			M. F.	1681 2277	.....	959 1915	.....	39.6 37.3	60.4 62.7	783 1510	.....
			M. F.	4988 3958	.....	956 3215	.....	35.3 37.8	64.7	727 1510	.....
			M. F.	1681 2277	.....	959 1915	.....	39.6 37.3	60.4 62.7	783 1510	.....
			M. F.	4988 3958	.....	956 3215	.....	35.3 37.8	64.7	727 1510	.....
			M. F.	1681 2277	.....	959 1915	.....	39.6 37.3	60.4 62.7	783 1510	.....
			M. F.	4988 3958	.....	956 3215	.....	35.3 37.8	64.7	727 1510	.....
			M. F.	1681 2277	.....	959 1915	.....	39.6 37.3	60.4 62.7	783 1510	.....
			M. F.	4988 3958	.....	956 3215	.....	35.3 37.8	64.7	727 1510	.....
			M. F.	1681 2277	.....	959 1915	.....	39.6 37.3	60.4 62.7	783 1510	.....
			M. F.	4988 3958	.....	956 3215	.....	35.3 37.8	64.7	727 1510	.....
			M. F.	1681 2277	.....	959 1915	.....	39.6 37.3	60.4 62.7	783 1510	.....
			M. F.	4988 3958	.....	956 3215	.....	35.3 37.8	64.7	727 1510	.....
			M. F.	1681 2277	.....	959 1915	.....	39.6 37.3	60.4 62.7	783 1510	.....
			M. F.	4988 3958	.....	956 3215	.....	35.3 37.8	64.7	727 1510	.....
			M. F.	1681 2277	.....	959 1915	.....	39.6 37.3	60.4 62.7	783 1510	.....
			M. F.	4988 3958	.....	956 3215	.....	35.3 37.8	64.7	727 1510	.....
			M. F.	1681 2277	.....	959 1915	.....	39.6 37.3	60.4 62.7	783 1510	.....
			M. F.	4988 3958	.....	956 3215	.....	35.3 37.8	64.7	727 1510	.....
			M. F.	1681 2277	.....	959 1915	.....	39.6 37.3	60.4 62.7	783 1510	.....
			M. F.	4988 3958	.....	956 3215	.....	35.3 37.8	64.7	727 1510	.....
			M. F.	1681 2277	.....	959 1915	.....	39.6 37.3	60.4 62.7	783 1510	.....
			M. F.	4988 3958	.....	956 3215	.....	35.3 37.8	64.7	727 1510	.....
			M. F.	1681 2277	.....	959 1915	.....	39.6 37.3	60.4 62.7	783 1510	.....
			M. F.	4988 3958	.....	956 3215	.....	35.3 37.8	64.7	727 1510	.....
			M. F.	1681 2277	.....	959 1915	.....	39.6 37.3	60.4 62.7	783 1510	.....
			M. F.	4988 3958	.....	956 3215	.....	35.3 37.8	64.7	727 1510	.....
			M. F.	1681 2277	.....	959 1915	.....	39.6 37.3	60.4 62.7	783 1510	.....
			M. F.	4988 3958	.....	956 3215	.....	35.3 37.8	64.7	727 1510	.....
			M. F.	1681 2277	.....	959 1915	.....	39.6 37.3	60.4 62.7	783 1510	.....
			M. F.	4988 3958	.....	956 3215	.....	35.3 37.8	64.7	727 1510	.....
			M. F.	1681 2277	.....	959 1915	.....	39.6 37.3	60.4 62.7	783 1510	.....
			M. F.	4988 3958	.....	956 3215	.....	35.3 37.8	64.7	727 1510	.....
			M. F.	1681 2277	.....	959 1915	.....	39.6 37.3	60.4 62.7	783 1510	.....
			M. F.	4988 3958	.....	956 3215	.....	35.3 37.8	64.7	727 1510	.....
			M. F.	1681 2277	.....	959 1915	.....	39.6 37.3	60.4 62.7	783 1510	.....
			M. F.	4988 3958	.....	956 3215	.....	35.3 37.8	64.7	727 1510	.....
			M. F.	1681 2277	.....	959 1915	.....	39.6 37.3	60.4 62.7	783 1510	.....
			M. F.	4988 3958	.....	956 3215	.....	35.3 37.8	64.7	727 1510	.....
			M. F.	1681 2277	.....	959 1915	.....	39.6 37.3	60.4 62.7	783 1510	.....
			M. F.	4988 3958	.....	956 3215	.....	35.3 37.8	64.7	727 1510	.....
			M. F.	1681 2277	.....	959 1915	.....	39.6 37.3	60.4 62.7	783 1510	.....
			M. F.	4988 3958	.....	956 3215	.....	35.3 37.8	64.7	727 1510	.....
			M. F.	1681 2277	.....	959 1915	.....	39.6 37.3	60.4 62.7	783 1510	.....
			M. F.	4988 3958	.....	956 3215	.....	35.3 37.8	64.7	727 1510	.....
			M. F.	1681 2277	.....	959 1915	.....	39.6 37.3	60.4 62.7	783 1510	.....
			M. F.	4988 3958	.....	956 3215	.....	35.3 37.8	64.7	727 1510	.....
			M. F.	1681 2277	.....	959 1915	.....	39.6 37.3	60.4 62.7	783 1510	.....
			M. F.	4988 3958	.....	956 3215	.....	35.3 37.8	64.7	727 1510	.....
			M. F.	1681 2277	.....	959 1915	.....	39.6 37.3	60.4 62.7	783 1510	.....
			M. F.	4988 3958	.....	956 3215	.....	35.3 37.8	64.7	727 1510	.....
			M. F.	1681 2277	.....	959 1915	.....	39.6 37.3	60.4 62.7	783 1510	.....
			M. F.	4988 3958	.....	956 3215	.....	35.3 37.8	64.7	727 1510	.....
			M. F.	1681 2277	.....	959 1915	.....	39.6 37.3	60.4 62.7	783 1510	.....
			M. F.	4988 3958	.....	956 3215	.....	35.3 37.8	64.7	727 1510	.....
			M. F.	1681 2277	.....	959 1915	.....	39.6 37.3	60.4 62.7	783 1510	.....
			M. F.	4988 3958	.....	956 3215	.....	35.3 37.8	64.7	727 1510	.....
			M. F.	1681 2277	.....	959 1915	.....	39.6 37.3	60.4 62.7	783 1510	.....
			M. F.	4988 3958	.....	956 3215	.....	35.3 37.8	64.7	727 1510	.....
			M. F.	1681 2277	.....	959 1915	.....	39.6 37.3	60.4 62.7	783 1510	.....
			M. F.	4988 3958	.....	956 3215	.....	35.3 37.8	64.7	727 1510	.....
			M. F.	1681 2277	.....	959 1915	.....	39.6 37.3	60.4 62.7	783 1510	.....
			M. F.	4988 3958	.....	956 3215	.....	35.3 37.8	64.7	727 1510	.....
			M. F.	1681 2277	.....	959 1915	.....	39.6 37.3	60.4 62.7	783 1510	.....
			M. F.	4988 3958	.....	956 3215	.....	35.3 37.8	64.7	727 1510	.....
			M. F.	1681 2277	.....	959 1915	.....	39.6 37.3	60.4 62.7	783 1510	.....
			M. F.	4988 3958	.....	956 3215	.....	35.3 37.8	64.7	727 1510	.....
			M. F.	1681 2277	.....	959 1915	.....	39.6 37.3	60.4 62.7	783 1510	.....
			M. F.	4988 3958	.....	956 3215	.....	35.3 37.8	64.7	727 1510	.....
			M. F.	1681 2277	.....	959 1915	.....	39.6 37.3	60.4 62.7	783 1510	.....

1870, 1871

1870, 1871

1870, 1871

ns-
des
ned
ent.
not
on,
or
his
em
ild

nd
ble

nal
he

he
nd

cc-
nd
he
ng
are
for

m-

ng

ng

ng

TABLE 83.—DATA OBTAINED FROM BAND COLLECTIONS AND LITERATURE OBSERVATIONS, WITH ACCOMPANYING CITATION DATA, OCT. 1, 1916

Date	From larvae collected 1919			From larvae collected 1918			Life-history data						Climatic data				
	Adults	Larvae under hand.	Pupa.	Adults	Larvae under hand.	Pupa.	Eggs laid.	Larvae hatched.	Larvae pupated.	Moths emerged.	Eggs laid.	Larvae hatched.	Larvae pupated.	Moths emerged.	Eggs laid.	Larvae hatched.	Mean daily temp.

Of the males, 39.6 per cent., and of the females, 35.3 per cent. transformed, 60.4 per cent. of the males and 64.7 per cent. of the females hibernated. Altogether, 37.3 per cent. of those collected transformed and 62.7 per cent. hibernated. Undoubtedly a much larger per cent. hibernated than the above figures indicate, since the collections do not include all the hibernating larvæ that left the fruit late in the season, after collections had ceased. It is probably true that three fourths or more of the larvæ which develop during a given season hibernate. This being the case it is very evident that if a very large per cent. of them did not perish during the winter, the first generation in the spring would be much larger than it usually is.

A daily record of the band collections, life-history observations, and climatic conditions at Olney in 1916 have been brought together in Table 33 for ready reference.

SUMMARY OF THE SEASONAL HISTORY, 1916

From the foregoing data and an occasional reference to original notes we can summarize quite accurately the seasonal history of the codling-moth for 1916 (Table 34).

Chart 2 gives a graphic representation of the seasonal history of the codling-moth in 1916, the daily temperatures above 50 degrees F., and the monthly rainfall.

The number of pupations observed daily are shown in the top section of the chart, the number of moths emerging daily in the second section from the top, the number of eggs deposited in the third, the number of larvæ hatched in the fourth, and the number of larvæ leaving the fruit in the fifth. The daily temperatures above 50 degrees F. are shown in the bottom section, beneath which is given the rainfall for each month.

The order of events in the seasonal history is indicated by the numbers from 1 to 12 in the chart.

Thus:	1	indicates	the	first	brood	of	pupæ
	2	"	"	"	"	"	adults
	3	"	"	"	"	"	eggs
	4	"	"	"	"	"	larvæ hatching and leaving the fruit
	5	"	"	second	"	"	pupæ
	6	"	"	"	"	"	adults
	7	"	"	"	"	"	eggs
	8	"	"	"	"	"	larvæ hatching and leaving the fruit
	9	"	"	third	"	"	pupæ
	10	"	"	"	"	"	adults
	11	"	"	"	"	"	eggs
	12	"	"	"	"	"	larvæ hatching and leaving the fruit.

TABLE 34—SEASONAL HISTORY OF THE CODLING-MOTH AT OLNEY, IN 1916

Generation	Period	Earliest	Relatively numerous	Maximum	Relatively numerous	Latest
Hibernating	Pupæ Adults	April 13 May 11	April 16 May 14	April 20 May 15	May 11 May 27	June 17 June 30
First	Eggs Young larvæ Mature larvæ Pupæ Adults	May 14 May 25 June 20 June 20 July 3	May 19 May 26 June 29 July 4 July 14	May 24 June 2 July 8 July 15 July 26	June 1 June 9 July 26 Aug. 2 Aug. 10	July 10* July 18* Aug. 9 Aug. 14 Aug. 24*
Second	Eggs Young larvæ Mature larvæ Pupæ Adults	July 6 July 12 July 31 Aug. 3 Aug. 12	July 15 July 21 Aug. 8 Aug. 11 Aug. 15	July 26 Aug. 1 Sept. 10 Aug. 17 Aug. 26	Aug. 13 Aug. 21 Sept. 25 Sept. 22 Sept. 7	Sept. 4 Sept. 21 Oct. 23† Sept. 3 Sept. 14*
Third	Eggs Young larvæ Mature larvæ	Aug. 14* Aug. 20* Oct. 1	Aug. 18 Aug. 28	Aug. 29 Sept. 12	Sept. 10 Sept. 13	Sept. 21 Sept. 15 Oct. 23†

* Dates computed.

† Last observation.



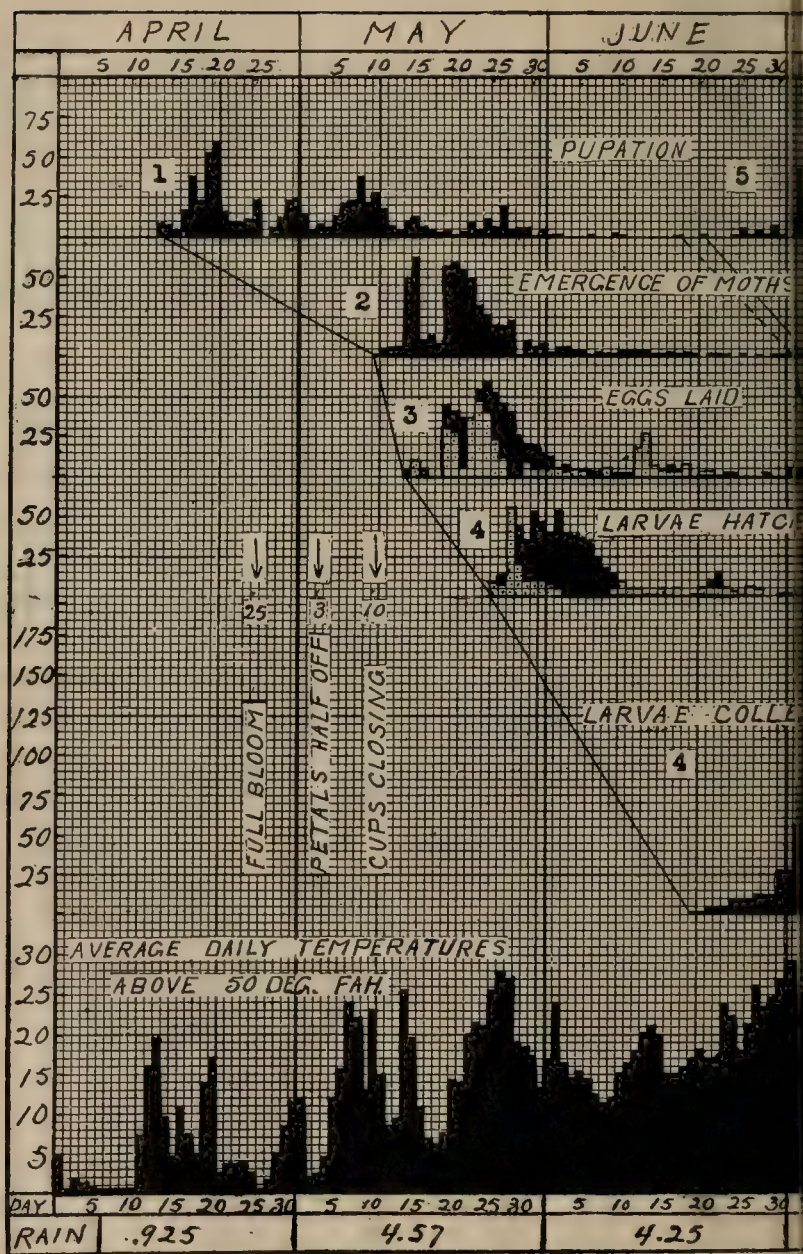
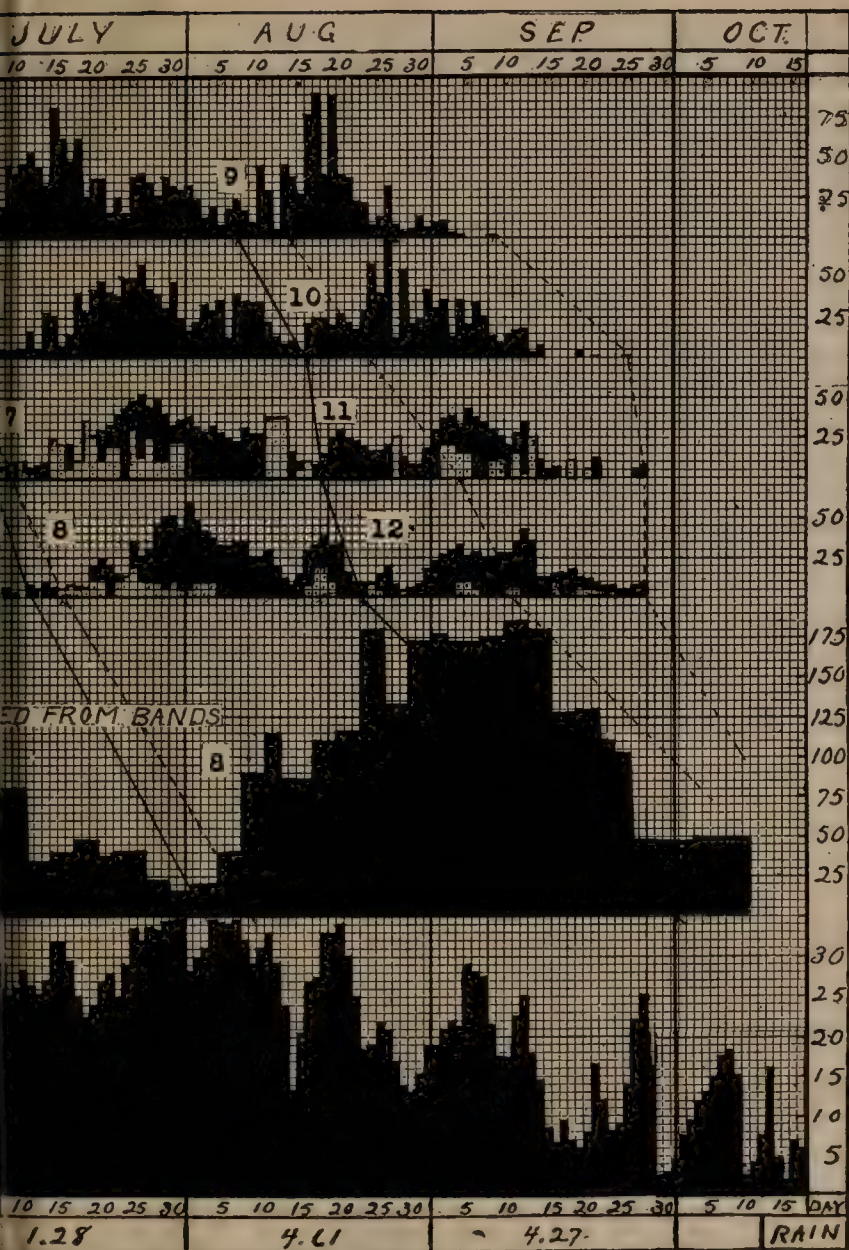


CHART 2. Seasonal history



codling-moth at Olney, 1916.



The third brood of pupæ is very clearly indicated by the marked increase in the number of pupations observed after August 8 or just after the second brood of larvæ began to leave the fruit, and the third brood of adults is as clearly indicated by the increase in the number of moths which emerged after August 15. The third broods of pupæ and of adults were nearly as large as the second broods, and no doubt the same held true for the third brood of larvæ. The black lines drawn obliquely downward through the chart connect the dates when each of the broods began, and the broken lines connect the dates on which the broods ended. The pupation of the first brood was very irregular, being frequently interrupted by cold periods. Owing to the cooler weather during April, May, and June, development was slower while the first brood was developing than later in the season, and for this reason there is little or no overlapping of the first and the second broods. The bulk of the first brood of pupæ, adults, eggs, and young larvæ had appeared fully a month before the second brood of each began to appear. The development of the second and third broods was much more rapid, and as a result there was a considerable overlapping of the broods, so much so in fact that pupæ, adults, eggs, and larvæ appeared daily, with little interruption, from the date of the appearance of the first of the second brood to the date of the appearance of the last of the third brood.

The average temperature for the month of June was about 5° below normal. This delayed the appearance of the second brood of pupæ, adults, eggs, and larvæ. Had normal temperatures prevailed during June the second and third broods would have appeared about one week earlier, and as a result the third brood would have been much larger.

RECORDS FOR SEVERAL LOCALITIES

TABLE 35

Generation	Stage	Ozark	Olney	Plainview	Spring-field
First	Pupa	April 10	April 13	April 13	April 13
	Moth	May 10	May 10	May 11	May 10
	Egg	May 14*	May 14		May 20
	Young larva	May 25	May 25		May 28
	Mature larva	June 10	June 20	June 26	June 29
Second	Pupa	June 10	June 24		July 3
	Moth	June 25*	July 3	July 8	July 11
	Egg	June 29*	July 6	July 10	July 13
	Young larva	July 4*	July 12	July 16	July 18
	Mature larva	July 26*	Aug. 3		Aug. 5
Third	Pupa	July 31*	Aug. 7		Aug. 9
	Moth	Aug. 8*	Aug. 16		Aug. 17
	Egg	Aug. 10*	Aug. 18		Aug. 19
	Young larva	Aug. 16*	Aug. 23		Aug. 29
	Mature larva	Aug. 26*	Oct. 1		

* Dates followed by an asterisk were computed.

Dates of the appearance of the different stages at Olney and other points in 1916 are given in Table 35, immediately preceding.

Olney is 75 miles, Plainview 108 miles, and Springfield 150 miles north of Ozark. The overwintering larvæ began to pupate at Ozark April 10, at Olney, Plainview, and Springfield April 13. The first moths emerged and the first eggs hatched on nearly the same dates at the four places. Larvæ of the second generation began to hatch about 8 days later at Olney, 12 days later at Plainview, and 14 days later at Springfield than at Ozark, and larvæ of the third generation began to hatch 7 days later at Olney and 13 days later at Springfield than at Ozark. Three generations were recorded at all four points. The third generation at Springfield was small as compared with the third generation at Olney.

SEASONAL HISTORY OF THE CODLING-MOTH, 1917

The methods of work pursued during 1915 and 1916 were continued in 1917. The work at Olney was closed in July, so complete records were not kept of the second and third generations at that place.

The season was not favorable for rapid development. While the mean temperature for April was about normal the temperature during the first half of the month was much below normal. May and June were cold months. The total accumulation of monthly degrees above 50 for April, May, June, July, and August was 86.9, the normal being 93.3.

LARGE-CAGE SERIES

First generation.—The material collected from cages in 1916 was not preserved, hence no record of the pupation and emergence of hibernating material was secured from cages. Hibernating larvæ collected from bands in 1916 began to pupate April 3. Moths began to emerge May 17 and continued to emerge till June 24. The first moths to emerge were not liberated in a large cage because the dates when the first eggs, larvæ, pupæ, and adults of the first generation appeared could be easily observed without using a cage; but the last moths to emerge from the hibernating band material were liberated in a large screen-cage to get the dates when the last eggs, larvæ, pupæ, and adults of the first generation appeared.

The first eggs of the first generation were laid May 19 and hatched June 1. The first mature larvæ left the fruit June 23 and pupated June 26, and the first moths emerged July 7. The last eggs of the first generation were noted in the large cage June 27. They were probably laid two or three days earlier. They hatched July 1. Mature larvæ were found under the band on the tree in this cage from July 13 to August 13. No observations were made to ascertain the dates of the last pupæ and adults.

TABLE 36.—RELATION OF TIME OF LEAVING THE FRUIT TO TIME OF EMERGENCE OF MOTHS OF THE HIBERNATING GENERATION OF 1916-17. OLNEY, 1917

Second generation.—The first moths of the first generation were liberated in cage No. 2 to rear the first individuals of the second generation.

Moths were liberated in cage No. 2, as follows:

Date	Males	Females
July 8	1	1
" 9	1	1
" 10	4	3
" 11	4	1
" 12	8	1
" 13	6	6
" 14	9	12

Eggs were found July 11 and young larvæ July 17. Daily observations ceased before larvæ began to leave the fruit in this cage.

Third generation.—The first eggs probably were laid about August 16 and hatched about August 22.

BAND COLLECTIONS

Hibernating generation, 1916-1917.—Of the 2687 adults of the hibernating generation emerging in 1917, 1258 were males and 1429 were females (Table 36). The average date of the emergence of the males was May 25, of the females May 27, and of the entire brood May 26. This was five days after the date of the maximum emergence. There was practically no difference between the dates of emergence of moths from larvæ which left the fruit in August and the emergence of those from larvæ which left the fruit later.

Collections made in 1917 (see Table 37).—The first mature larvæ were taken under bands at Springfield only two days later than at Olney. The second generation of larvæ began to leave the fruit at Olney between July 23 and July 30, but, unfortunately, there was a period of seven days here between the records, and the exact date can not be accurately determined. The bands at Springfield were torn from the trees some time between August 4 and August 12 by some one unknown, and hence the date when the second generation began to leave the fruit at Springfield is also uncertain.

The falling off in the number of larvæ taken at Springfield after October 6 was due largely to the fact that the apples were picked from half of the trees soon after that date.

Complete records of pupation, and the emergence of moths from band material were not preserved. At Ozark the first larvæ left the apples June 18 and the first moth emerged July 1. At Olney the first larvæ left the fruit June 23, and pupated June 26, the first moths emerging July 7. At Springfield the first larvæ left the fruit June 25, and pupated June 28, the first moths emerging July 9. (Table 40, p. 277.)

Observations ceased too early to get complete data on pupation and emergence of the second generation, or on the third generation. There is no doubt, however, that there was a third generation at Olney. Larvæ of the second generation began to leave the fruit about August 4, and since transforming of larvæ usually continues till the end of August, no doubt many of the first larvæ of the second generation transformed and produced a partial third generation. The first eggs of the third generation were laid about August 23 and hatched about August 31.

TABLE 37—RECORD OF LARVÆ COLLECTED UNDER BANDS AT OZARK, OLNEY, AND SPRINGFIELD IN 1917

Date	Number of larvæ collected		
	Ozark	Olney	Springfield
June 21	2		
" 23	2	3	
" 24		1	
" 25			3
" 26	9	26	
" 29	8	43	
" 30			29
July 2			
" 5	15	117	
" 7	3	55	65
" 11	4	91	
" 13	5		96
" 14		46	
" 17	6	26	
" 19		23	
" 20			116
" 21	7	8	
" 23	2	4	
" 28	2		125
" 30		44	
Aug. 2	6		62
" 6	9	182	Bands off*
" 13	3	243	Bands off*
" 17	14		
" 20		362	
" 22	12		
" 24	11		114
" 29	13		365
Sept. 1	13		
" 4	15		544
" 9	42		
" 21	31		1860
" 28	14		1334
Oct. 6	16		1395
" 13			299
" 18			500
" 30	54		51

* See p. 273, line 13 from bottom.

TABLE 24. DATA OBTAINED FROM BAYO CATCHPANS AND LIFE HISTORY OBSERVATIONS

WILLACAMAC, CANADA DATA DRY, 1917

Date	From larva collected 1916		From larva collected 1917		Eggs laid	Life history data		Mean temp.	Climate data		Days to pupa
	Pupa	Adults	Number collected	Adults		Life span	Lat.		Wind	Temp.	
Apr 3											
" 4											
" 5											
" 6											
" 7											
" 8											
" 9											
" 10											
" 11											
" 12											
" 13											
" 14											
" 15											
" 16											
" 17											
" 18											
" 19											
" 20											
" 21											
" 22											
" 23											
" 24											
" 25											
" 26											
" 27											
" 28											
" 29											
" 30											
" 31											
" 1											
" 2											
" 3											
" 4											
" 5											
" 6											
" 7											
" 8											
" 9											
" 10											
" 11											
" 12											
" 13											
" 14											
" 15											
" 16											
" 17											
" 18											
" 19											
" 20											
" 21											
" 22											
" 23											
" 24											
" 25											
" 26											
" 27											
" 28											
" 29											
" 30											
" 31											
" 1											
" 2											
" 3											
" 4											
" 5											
" 6											
" 7											
" 8											
" 9											
" 10											
" 11											
" 12											
" 13											
" 14											
" 15											
" 16											
" 17											
" 18											
" 19											
" 20											
" 21											
" 22											
" 23											
" 24											
" 25											
" 26											
" 27											
" 28											
" 29											
" 30											
" 31											
" 1											
" 2											
" 3											
" 4											
" 5											
" 6											
" 7											
" 8											
" 9											
" 10											
" 11											
" 12											
" 13											
" 14											
" 15											
" 16											
" 17											
" 18											
" 19											
" 20											
" 21											
" 22											
" 23											
" 24											
" 25											
" 26											
" 27											
" 28											
" 29											
" 30											
" 31											
" 1											
" 2											
" 3											
" 4											
" 5											
" 6											
" 7											
" 8											
" 9											
" 10											
" 11											
" 12											
" 13											
" 14											
" 15											
" 16											
" 17											
" 18											
" 19											
" 20											
" 21											
" 22											
" 23											
" 24											
" 25											
" 26											
" 27											
" 28											
" 29											
" 30											
" 31											
" 1											
" 2											
" 3											
" 4											
" 5											
" 6											
" 7											
" 8											
" 9											
" 10											
" 11											
" 12											
" 13											
" 14											
" 15											
" 16											
" 17											
" 18											
" 19											
" 20											
" 21											
" 22											
" 23											
" 24											
" 25											
" 26											
" 27											
" 28											
" 29											
" 30											
" 31											
" 1											
" 2											
" 3											
" 4											
" 5											
" 6											
" 7											
" 8											
" 9											
" 10											
" 11											
" 12											
" 13											
" 14											
" 15											
" 16											
" 17											
" 18											
" 19											
" 20											
" 21											
" 22											
" 23											
" 24											

A daily record of the band collections, life-history observations, and climatic conditions at Olney in 1917 have been brought together in Table 38 for ready reference.

SUMMARY OF THE SEASONAL HISTORY, 1917

From the foregoing data, the seasonal history of the codling-moth at Olney can be quite accurately determined (Table 39).

Chart 3 represents in graphic form, the data given in Table 39. These data are disconnected and meager for the second and third generations. The position and form of the curved lines in the chart, representing the relative number of eggs and young larvæ of the first generation and the number of the different stages of the second and third generations, are based upon estimates only, since complete daily records were not kept.

The bulk of the hibernating larvæ pupated during the unusually warm period in the third week of April; the bulk of the adults emerged during the last two weeks of May; the bulk of the eggs of the first generation were laid during the last ten days of May and the first week in June; and the bulk of the larvæ hatched during the first three weeks of June. There was no overlapping of the first and second generations except in the larval stage.

RELATION OF TEMPERATURE TO THE SEASONAL HISTORY OF THE CODLING-MOTH

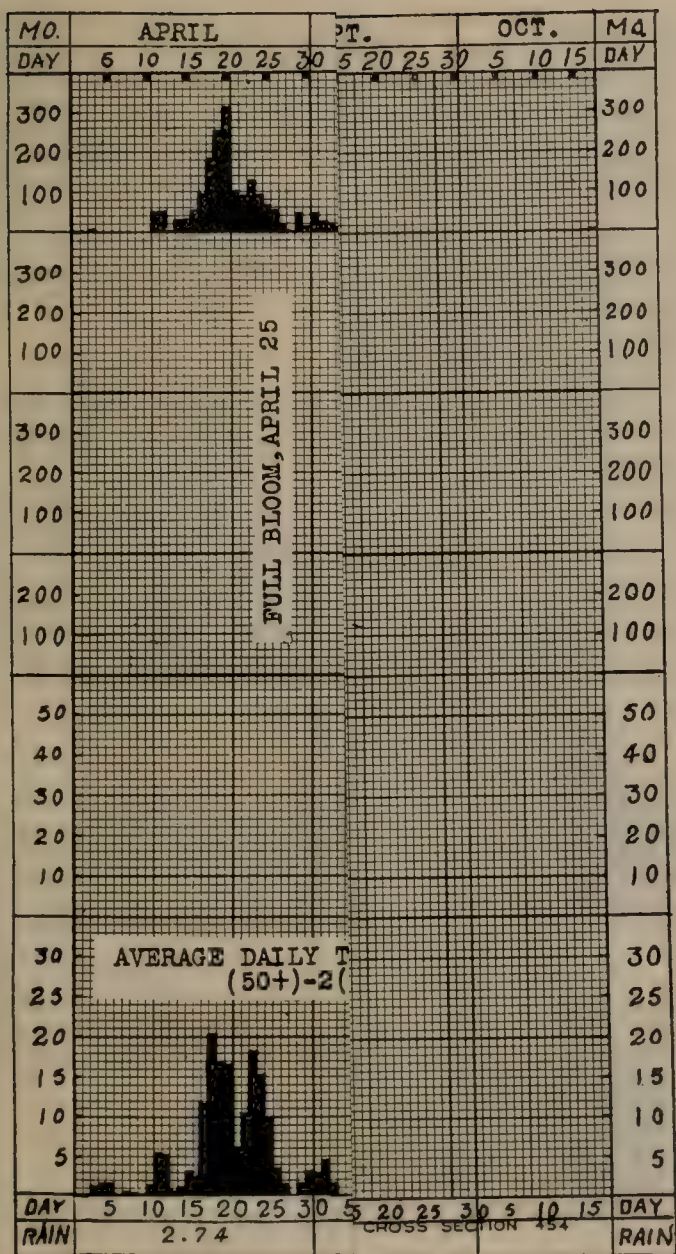
It has already been shown that there is quite a constant relation between the temperatures above 50 degrees when corrected for retarding temperatures above 86 degrees and the length of time required to bring the insect through the egg, larval, and pupal periods. This applies to all the periods except the larval period of the hibernating larvæ. The length of time the hibernating larvæ remain in the cocoon is independent of the day-degrees which accumulate between the time when hibernation begins and the winter months. It is found, however, that there is a more or less definite relation between the average daily temperatures above 50 degrees in the spring months and the dates when the first pupæ and the first adults appear. There is a very great individual variation in this respect, as will be seen by referring to the last column of Tables 19 and 20.* In Table 19, it will be seen that the hibernating larvæ began to pupate when the sum of the day-degrees above 50 degrees F. after January 1 amounted to 115; the accumulations for the others ranged from 115 to 356, the average being 186. In Table 20 it will be seen that the hibernating larvæ of 1916-1917 began to pupate when the sum of the day-degrees above 50 degrees F. amounted to 104. The others varied from 104 to 355, the average being 190.

* Tables 9-25 follow p. 253.

TABLE 39.—SEASONAL HISTORY OF THE CODLING-MOTH AT OLNEY, 1917

Generation	Period	Earliest	Relatively numerous	Maximum	Relatively numerous	Latest
Hibernating	Pupæ Adults	April 3 May 17	April 11 May 19	April 20 May 21	April 26 June 1	June 11 June 21
First	Eggs Young larvæ Mature larvæ Pupæ Adults	May 20 June 1 June 23 June 27 July 7	May 21 June 2 June 26 June 30 July 10	May 25 June 8* July 6 July 10* July 20*	June 3 June 10 July 19 July 22* Aug. 2	June 27 July 1 Aug. 6* Aug. 11* Aug. 20*
Second	Eggs Young larvæ Mature larvæ Pupæ Adults	July 11 July 17 Aug. 4* Aug. 8* Aug. 21*		.		Aug. 23*
Third	Eggs Young larvæ	Aug. 23* Aug. 31*				

* Computed.



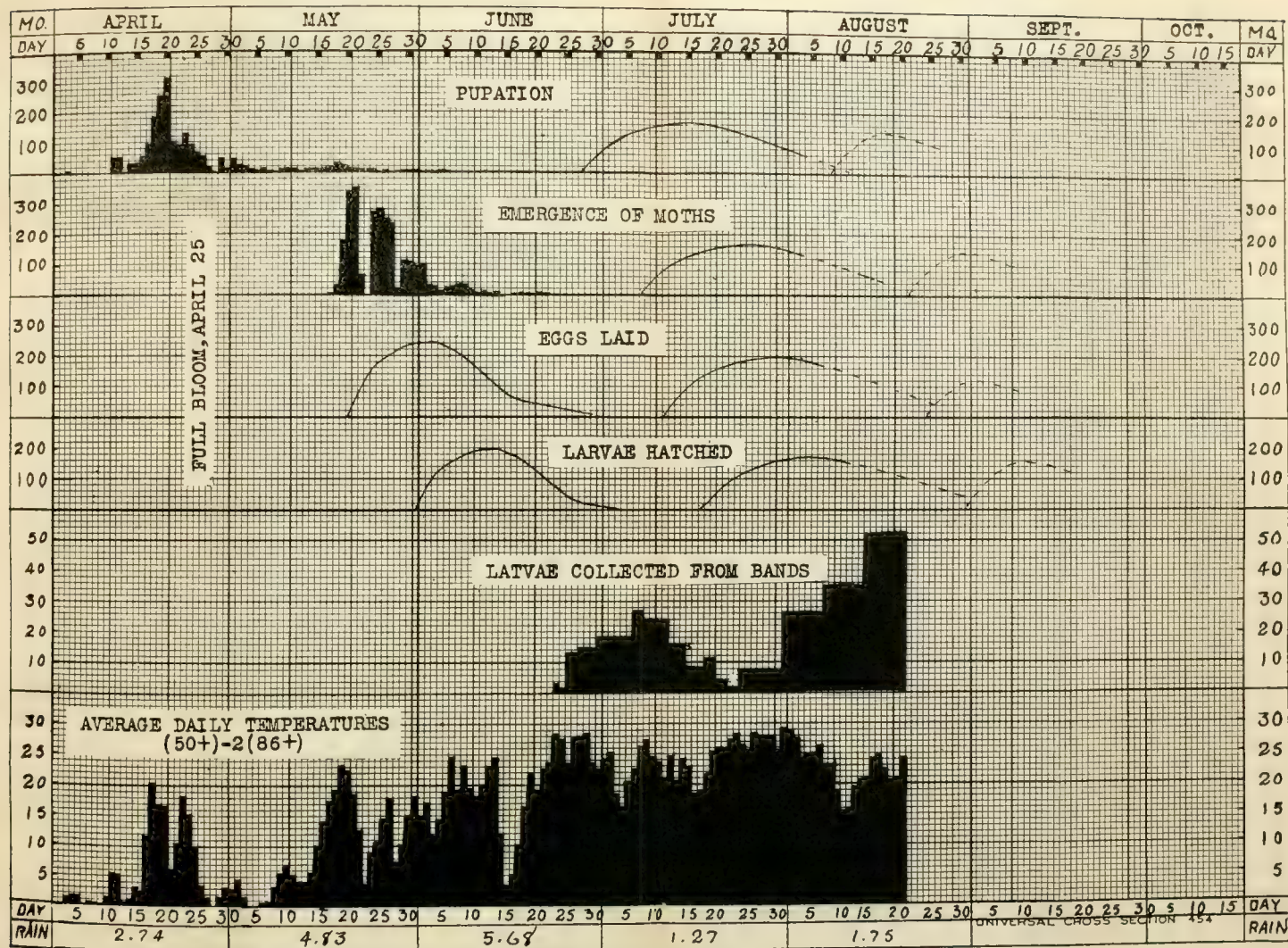


CHART 3. Seasonal history of the codling-moth at Olney, 1917.

Date	Stage	1915		1916		1917	
		Daily deg.-days	Total deg.-days	Daily deg.-days	Total deg.-days	Daily deg.-days	Total deg.-days
Mar. 31							
Apr. 1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							
26							
27							
28							
29							
30							
May 1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							
26							
27							
28							
29							
30							
June 1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							
26							
27							
28							
29							
30							
July 1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							
26							
27							
28							
29							
30							
Aug. 1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							
26							
27							
28							
29							
30							
Sept. 1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							
26							
27							
28							
29							
30							
Oct. 1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							
26							
27							
28							
29							
30							
Nov. 1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							
26							
27							
28							
29							
30							
Dec. 1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							
26							
27							
28							
29							
30							

TABLE 40—DATES OF THE APPEARANCE OF THE FIRST INDIVIDUALS OF THE BROODS OF THE CODLING-MOTH AT OZARK, OLNEY, AND SPRINGFIELD IN 1917

Generation	Stage	Ozark	Olney	Springfield
Hibernating	Adults	May 12	May 17	May 17
First	Eggs	May 19	May 20	
	Larvæ	May 27	June 1	
	Mature larvæ	June 18	June 23	June 25
	Adults	July 1	July 7	July 9
Second	Eggs		July 11	
	Larvæ		July 17	

To show the relation between the time of the appearance of the first individuals of each of the broods throughout the season at Olney Table 41 has been prepared.

The same data were worked out for Ozark in 1915, Springfield in 1916 and 1918, and Siloam Springs, Arkansas, for 1908, and the results are summarized in Table 42.

From the averages in the last column of Table 42 we find, by a little calculation, that the average accumulation of effective day-degrees from the time of the appearance of the first individuals of the first brood of pupæ, adults, eggs, and larvæ to the time of appearance of the first individuals of the second brood of the same is 979, and that the average accumulation between the time of appearance of the first individuals of the second brood of pupæ, adults, eggs, and larvæ and the time of appearance of the first individuals of the third brood of the same is 1082, the average accumulation for the complete life cycle, that is, for the period between the time of the appearance of the first eggs, larvæ, pupæ, or adults of one generation and the first eggs, larvæ, pupæ, or adults of the next generation, being 1030.

From studies on the relation of temperature to the development of the different stages and to the whole development period in the life history, we know that there is practically no difference between the number of effective day-degrees which accumulate during these periods in the different generations. The differences shown by the data in the table are therefore undoubtedly due to the comparatively small number of observations on which the averages were based and to the fact that some of the observations were made in connection with breeding experiments in which comparatively small numbers of individuals were used. The dates on which the first larvæ of the first generation entered the fruit were determined by observations on individuals reared from hibernating larvæ, and since the number of individuals thus used was very small as compared with the whole number in the orchard, no doubt larvæ began to enter the fruit in the orchard before the first larvæ were secured in the experiments. The dates when the first larvæ of the second genera-

TABLE 42—ACCUMULATED EFFECTIVE DAY-DEGREE AT THE TIME OF THE OBSERVED APPEARANCE OF THE FIRST INDIVIDUALS OF EACH BROOD

Generation	Stage	Olney		Ozark	Springfield		Siloam Springs, Ark.*	Average
Hibernating	Pupa Adult	1915	1916	1917	1916	1918	1908	
			115	104	108	110		109
		315	356	355	313	345	324	339
First	Egg	422	415	420	400		371	406
	Larva	585	581	573	574		623	578
	Mature larva	968	967	972	1082			970
	Pupa	1075	1034	1079	1169	1066	1024	1074
	Adult	1309	1337	1307	1399	1272	1285	1308
Second	Egg	1415	1410	1403	1454		1389	1414
	Larva	1557	1566	1532	1602		1528	1551
	Mature larva	2079	2079	2009†	2134		2034	2065
	Pupa	2168	2161	2106†	2246			2169
	Adult	2429	2418	2377†	2430	2302	2423	2387
Third	Egg	2471	2455	2424†	2490		2477	2471
	Larva	2645	2618	2576†	2688		2643	2632

* Data in this column were obtained by the use of the 1908 records of the U. S. Weather Bureau for Fayetteville, Arkansas, and the seasonal history records of the codling-moth as given by E. L. Jenne in Bulletin No. 80, Part I, of the Bureau of Entomology, U. S. Department of Agriculture, 1909.

† Numbers followed by a dagger were computed.

tion entered the fruit was determined from observations on individuals secured from band collections. These were abundant enough to give us the dates with a fair degree of accuracy. The number of effective day-degrees, 1551, or, to use round numbers, 1550, given for this event in the table may be considered as approximately correct and will be used as a basis for making corrections in the table. The dates when the first larvæ of the third generation entered the fruit were determined from a comparatively small number of individuals isolated for the purpose of life history studies, and for this reason it is quite certain that the dates thus obtained were somewhat later than the true dates.

It is impossible to estimate with any degree of accuracy how much of an error was made in determining dates from a too limited amount of material, but we can, by using data procured by studies on the relation of temperature to the different stages and to the complete development period, determine the approximate minimum effective day-degrees which accumulate during the complete life cycle; and by using 1550 as the total effective day-degrees at the time when the first larvæ of the second generation appear we can determine the total effective day-degrees for the date on which the first egg, larvæ, pupæ, and adults of the three generations may be expected to appear.

From our studies on the relation of temperature to the development of the three stages we concluded (see page 280) that the minimum accumulation for the three stages was about 939, the average 1101, and the maximum about 1317; and from our studies on the life history of 348 individuals we concluded that the minimum accumulation for the period of development was about 950, the average 1120, and the maximum about 1350 (see page 259). To get the total accumulation for the complete life cycle, it will be necessary to add to these minima, averages, and maxima about 50, 75, and 250, respectively, because the deposition of the first eggs, the time of maximum oviposition, and the laying of the last eggs do not occur until about the first, the third, and the tenth day, respectively, after the emergence of the female. (Table 43.)

None of the minima, 989, 1000, and 1030, obtained for the complete life cycle by the different methods was determined with absolute accuracy, but they were based on actual observations, and the fact that they do not differ very widely indicates that they are approximately correct. For practical purposes either one might be used as the minimum, but the second minimum, 1000, being nearly the average of the three is perhaps more nearly correct than the others, and it will be used as the basis for the discussion which follows.

By dividing the 1000 effective day-degrees into parts proportional to the minimum effective day-degrees required for the egg, larval, and pupal periods, making allowance for the period elapsing between the time of the emergence of the adult female and the deposition of the first eggs, and by taking 1550 (Table 42) as approximately the correct accumulation at the time when the larvæ of the second generation begin

to enter the fruit, we can construct a consistent table showing the approximate accumulations which indicate the time when the first pupæ, adults, eggs, and larvæ of the three generations may be expected to appear. Table 44, however, for the present, must be regarded as only a somewhat close approximation to the correct accumulations. It may be necessary to make some changes as a result of further observations.

TABLE 43—ACCUMULATION OF EFFECTIVE DAY-DEGREES DURING STAGES, DURING ENTIRE DEVELOPMENT PERIOD, AND DURING THE COMPLETE LIFE CYCLE

	Period	Accumulation		
		Minimum	Average	Maximum
Stages	Egg	156	163	170
	Larva	527	673	873
	Pupa	256	265	274
	(Total)	939	1101	1317
	Adult to egg	50	75	250
Life history	Life cycle	989	1176	1567
	Development period	950	1120	1350
	Adult to egg	50	75	250
	Life cycle	1000	1195	1600
Seasonal history	Life cycle	1030		

TABLE 44—ACCUMULATED EFFECTIVE DAY-DEGREES WHICH INDICATE THE TIME WHEN THE FIRST EGGS, LARVAE, PUPAE, AND ADULTS MAY BE EXPECTED TO APPEAR

Generation	Stage	Day-degrees
Hibernating	First pupæ	82
	First adults	340
First generation	First eggs	392
	First larvæ	550
	First pupæ	1082
	First adults	1342
Second generation	First eggs	1392
	First larvæ	1550
	First pupæ	2082
	First adults	2342
Third generation	First eggs	2392
	First larvæ	2550

TABLE 45—AVERAGE NORMAL DAILY EFFECTIVE DAY-DEGREES, ACCUMULATIONS OF THE SAME, AND DATES WHEN THE FIRST INDIVIDUALS OF THE DIFFERENT STAGES OF EACH GENERATION MAY BE EXPECTED TO APPEAR AT OLNEY IN A NORMAL SEASON

Date.	March.			April.			May.			June.			July.			August.		
	Daily effective day-degrees.	Total effective day-degrees.	Stage.	Daily effective day-degrees.	Total effective day-degrees.	Stage.	Daily effective day-degrees.	Total effective day-degrees.	Stage.	Daily effective day-degrees.	Total effective day-degrees.	Stage.	Daily effective day-degrees.	Total effective day-degrees.	Stage.	Daily effective day-degrees.	Total effective day-degrees.	Stage.
1	1	1		5	91		11	296		20	789		25	1465		26	2264	
2	1	2		5	96		11	307		20	809		25	1490		26	2290	
3	1	3		5	101		12	319		20	829		25	1515		26	2316	
4	1	4		5	106		12	331		20	849		25	1540	Larva	26	2342	Adult
5	1	5		5	111		13	344	Adult	20	869		25	1565		26	2368	
6	1	6		5	116		13	357		20	899		25	1590		25	2393	Egg
7	1	7		5	121		13	370		20	909		26	1616		25	2418	
8	2	9		5	126		14	384		20	929		26	1642		25	2443	
9	2	11		5	131		14	398	Egg	21	950		26	1668		25	2468	
10	2	13		5	136		14	412		21	971		26	1694		25	2493	
11	2	15		5	141		14	426		21	992		26	1720		25	2518	
12	2	17		5	146		15	441		21	1013		26	1746		25	2543	Larva
13	3	20		6	152		15	456		22	1035		27	1773		25	2568	
14	3	23		6	158		15	471		22	1057		27	1800		25	2593	
15	3	26		6	164		15	486		22	1079	Pupa	27	1827		26	2619	
16	3	29		6	170		15	501		22	1101		27	1854		26	2645	
17	3	32		6	176		16	517		22	1123		27	1881		26	2671	
18	3	35		7	183		16	533		23	1146		27	1908		26	2697	
19	3	38		7	190		16	549	Larva	23	1169		27	1935		26	2723	
20	4	42		7	197		17	566		23	1192		26	1961		25	2748	
21	4	46		7	204		17	583		24	1216		26	1987		24	2772	
22	4	50		8	212		17	600		24	1240		26	2013		24	2796	
23	4	54		8	220		18	618		25	1265		25	2038		24	2720	
24	4	58		9	229		18	636		25	1290		25	2063		24	2844	
25	4	62		9	238		18	654		25	1315		25	2088	Pupa	24	2868	
26	4	66		9	247		18	672		25	1340	Adult	25	2113		23	2891	
27	4	70		9	256		19	691		25	1365		25	2138		22	2913	
28	4	74		9	265		19	710		25	1390	Egg	25	2163		22	2935	
29	4	78		10	275		19	729		25	1415		25	2188		22	2957	
30	4	82	Pupa	10	285		20	749		25	1440		25	2213		22	2979	
31	4	86					20	769					25	2238		22	3001	

1900	1901	1902	1903
1900	1901	1902	1903
1900	1901	1902	1903
1900	1901	1902	1903
1900	1901	1902	1903
1900	1901	1902	1903
1900	1901	1902	1903
1900	1901	1902	1903
1900	1901	1902	1903
1900	1901	1902	1903
1900	1901	1902	1903
1900	1901	1902	1903

METHOD OF FORECASTING DATES WHEN THE DIFFERENT STAGES
OF THE SEVERAL GENERATIONS MAY BE EXPECTED TO APPEAR
AT ANY GIVEN PLACE IN A NORMAL SEASON

By ascertaining the normal daily effective day-degrees at any point in the state throughout the season and ascertaining the total sums of the daily accumulations for each day of the season and comparing the sums on the different dates with Table 44, we can ascertain the approximate dates when the different stages of each generation may be expected to appear. Table 45 gives the normal daily effective day-degrees, the total effective day-degrees, and the dates on which the first individuals of the stages of each generation normally appear at Olney, Illinois.

This table was computed from the maximum and minimum readings of the U. S. Weather Bureau at Olney from 1901 to 1916 inclusive by the formulæ given on page 283. In all of these computations the daily effective day-degrees were taken as the average degrees above 50° F. diminished by twice the average degrees above 86.

It is not to be expected that the first eggs, larvæ, pupæ, and adults will appear in any locality on the exact dates shown in a table of the normal accumulations of effective day-degrees for that locality. Such tables will give only the approximate dates. There are many factors which may influence the time of appearance: there are always periods during every season when the temperatures are not normal; there are situations in every locality in which the temperatures differ from those of the place where the recording instrument is located, such as steep northern and steep southern slopes, and differences in altitudes in hilly countries; and pupæ on the south side of the trunks of trees will be subjected to greater heat than those on the north side.

There is no practical method by which all the local factors may be taken into account, but the seasonal variations may be anticipated by keeping a daily record of the total accumulation of effective day-degrees in each of the fruit-growing sections; and dates when the first larvæ of each generation may be expected to enter the fruit may be anticipated however abnormal the weather may be. When the accumulations amount to 390, 1290, and 2280 the first larvæ of the first, second, and third generations, respectively, may be expected to enter the fruit in about 10 days. (See Table 51, p. 289.)

Table 43 (p. 280) shows that the average accumulation of effective day-degrees for the complete life cycle, as ascertained by a study of the different stages, is 1176, the maximum being about 1567, and that by a study of the life history the average accumulation is 1195, the maximum being about 1600. These differences arise partly from the fact that in the former case 86, 85, and 87 degrees F. were used as the degrees of maximum rate of development of the egg, larva, and pupa, respectively, whereas in the latter case 86 was used for each of the stages. Since it is much more convenient to use 86, 1195 should be used as the approximate average.

It follows that since the first and the second generations are almost complete in the southern half of Illinois, if the larvæ of the first generation are observed to be entering the fruit in large numbers on a certain date, larvæ of the second generation will be entering the fruit in large numbers after an interval during which the accumulated effective day-degrees have reached 1195, unless delaying factors, such as parasites, rainy weather at hatching time, or other cause which might occasion great mortality of eggs, larvæ, or pupæ, should intervene. This would not hold true for the third generation, since it is not complete, for, at best, only a small proportion of the larvæ of the second generation transform.

The maximum number of effective day-degrees which may accumulate between the deposition of an egg of one generation and the deposition of an egg of the next generation is about 1600. If a number of eggs are deposited on the same day the deposition of eggs by females developed from them will be extended over a period during which the accumulation of effective day-degrees ranges from 1000 to 1600, which corresponds to a period of about 20 days. This accounts largely for the overlapping of the second and third generations notwithstanding the fact that the first and second do not overlap.

HOW TO COMPUTE EFFECTIVE DAY-DEGREES

One of the main objects of this investigation was to find, if possible, a single factor in terms of which the progress of the seasonal history of the insect could be followed and even predicted long enough beforehand to be of practical value. *Apparently we have found that factor in temperature expressed in terms of effective day-degrees as the unit.* Humidity, evaporation, and rainfall may affect the rate of development to some extent, but in the case of the codling-moth these factors have such a small influence under out-of-door conditions that for practical purposes they may be disregarded, leaving temperature as the single factor to be taken into account.

The temperatures that are to be taken into account are the temperatures above 50 degrees and those above 86. To ascertain the number of effective day-degrees that have accumulated during any given day, first find the average degrees above 50 degrees F., then the average degrees above 86 degrees, multiply the latter by two and subtract the product from the former. The result will be the effective day-degrees.

To compute the effective day-degrees, accurate thermograph records should be kept. The average daily temperatures above 50 degrees F. can be computed by adding together the hourly readings above 50 and dividing the sum by 24, and the average daily temperatures above 86 can be computed in the same manner. If the drum type of thermograph be used the temperature curve above 50 and above 86 may be integrated by means of a planimeter, expressing the result as hourly-degree units, then by dividing the totals for each day by 24, the average hourly-degrees above 50 and 86 may be ascertained, which are the day-degrees in each case. Subtracting from the day-degrees above 50 twice the day-degrees above 86 gives the number of effective day-degrees.

In case thermograph records are not available the effective day-degrees can be determined approximately from maximum and minimum readings by the use of the following formulæ proposed by Dr. S. A. Forbes.

Formulae for computing the average day-degrees above any given temperature, using the maximum temperature, and the minimum temperatures preceding and following it.

a = Number of degrees that the first minimum is above or below the given temperature.

b = Number of degrees that the second minimum is above or below the given temperature.

c = Number of degrees that the maximum is above the given temperature.

x = Number of day-degrees above the given temperature.

I. When both minima are at or above the given temperature,

$$x = \frac{a + b + 2c}{4}.$$

II. When the first minimum is below the given temperature,

$$x = \frac{b + c}{4} + \frac{c^2}{4(a + c)}.$$

III. When the second minimum is below the given temperature,

$$x = \frac{a + c}{4} + \frac{c^2}{4(b + c)}.$$

IV. When both minima are below the given temperature,

$$x = \frac{c^2}{4(a + c)} + \frac{c^2}{4(b + c)}.$$

When the thermograph is used it should be kept correct by checking it up daily with the maximum and minimum thermometers, and the recording instrument should be kept in a place which has the same conditions as to temperature as the orchards to which the records are to be applied. It is very evident that the maximum and minimum readings taken in the heart of a city would not give readings that would apply to adjacent country districts.

RELATION OF TEMPERATURE TO TIME WHEN LARVÆ HIBERNATE

In the spring, hibernating larvæ will begin to transform as soon as temperatures rise above 52° F., but after midsummer, soon after the temperatures begin to fall, maturing larvæ cease to transform long before the temperatures fall below the 52 point.

Generally, larvæ that mature prior to August 1 transform; those that mature after September 1, hibernate; and of those that mature during August some hibernate and some transform, the percentage of those that hibernate usually increasing as the month advances, the rate of increase depending upon the temperatures.

The time when hibernation takes place is determined largely by the habit of the species, but it may be somewhat modified by temperatures. While at Olney hibernation did not usually take place until August, a few unusually cool days caused some larvæ to hibernate as early as the first week in July in 1915, and in 1916 hibernation was delayed till the middle of August by continuous warm weather. Some larvæ hibernate any time after midsummer when the minimum daily temperatures fall to 60° or below and the mean daily temperatures to about 70° or below; other larvæ do not hibernate until such temperatures have prevailed for two or three weeks. During the latter half of August hibernation is induced much more readily than earlier in the month, and with rare exceptions larvæ maturing after September 1 hibernate irrespective of temperatures.

Table 46 illustrates what has just been said concerning hibernation.

Note that in 1915, 4.4 per cent. of the larvæ which matured during the period from July 4 to July 7, at the close of a week of unusually cool weather, hibernated. Another period of cool weather ended with July 25, and 5 per cent. of the larvæ maturing during the period from July 25 to July 28 hibernated. The next period of cool weather began August 4, and 7 per cent. of the larvæ maturing during the period from August 4 to August 7 hibernated. From this time on, the mean daily temperatures remained near 70° or below, and the percentage of hibernating larvæ increased very rapidly until August 27. All larvæ under observation maturing after this date hibernated with the exception of two. The two larvæ which transformed, matured during a period of twelve exceptionally warm days following September 7.

In 1916 there were no cool days in July and none in August until the 14th. No larvæ hibernated in July. A few that hibernated prior to August 14, hibernated apparently purely from habit. The two cool days of August 14 and 15 may have hastened hibernation, but the percentage of those that hibernated increased rapidly from the 16th to the 22d, although the weather was unusually warm, showing that after the middle of August larvæ will yield to their habit regardless of temperatures. The delay in the time of hibernation in 1916, as compared with 1915, was undoubtedly due to the higher temperatures in 1916 during August.

RELATION OF HUMIDITY AND EVAPORATION TO THE RATE OF DEVELOPMENT OF THE CODLING-MOTH

When we began the preliminary study of our accumulated data on this subject they indicated clearly that temperature was the controlling factor in determining the rate of development of the stages of the codling-moth, and that humidity and evaporation had at most only a very

1. The first part of the report

(1)

1. The first part of the report

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

TABLE 46.—PERCENTAGE OF LARVAE COLLECTED AT ONSET FROM BANDS AT INTERVALS OF 2-4 DAYS WHICH HIBERNATED, WITH RECORD OF TEMPERATURES

Date of collection.	1915.						1916.					
	Temperature.			Per cent. hibernated.			Temperature.			Per cent. hibernated.		
	Max.	Min.	Mean	Male	Female	M. & F.	Max.	Min.	Mean	M.	F.	M. & F.
July 1	90	64	71				87	69	79			
" 2	83	62	72				92	67	80			
" 3	72	62	70				89	71	80			
" 4	77	58	65				85	65	75			
" 5	74	50	61	5.8	3.3	4.4	85	61	74			
" 6	77	53	66				86	61	77			
" 7	81	62	69				89	64	77			
" 8	69	64	68				86	66	76			
" 9	73	60	68				86	66	76			
" 10	84	67	72				87	65	76			
" 11	86	65	72				91	68	78			
" 12	81	68	74				78	73	77			
" 13	87	69	77				88	68	76			
" 14	90	72	80				91	72	82			
" 15	91	74	83				94	71	82			
" 16	90	75	82				94	70	81			
" 17	88	75	80				93	71	81			
" 18	89	73	81				92	71	80			
" 19	86	71	77				90	70	78			
" 20	80	71	77				87	70	76			
" 21	78	58	69				90	61	76			
" 22	79	58	69				94	65	79			
" 23	82	58	70				94	65	79			
" 24	82	61	71				96	67	81			
" 25	84	64	72				97	68	82			
" 26	86	70	76		6.7	5.	99	70	84			
" 27	87	70	77				97	70	84			
" 28	90	70	79				98	75	86			
" 29	82	72	79				95	73	84			
" 30	87	73	79				99	76	86			
" 31	91	74	82				83	71	77			
AUG. 1	86	72	78				91	70	79			
" 2	84	71	76				95	73	84			
" 3	80	73	76				98	70	81			
" 4	70	61	65				95	73	84			
" 5	75	56	64	7.	1.	7.	97	73	84			
" 6	82	60	70				97	74	84			
" 7	84	57	70				97	73	85			
" 8	85	68	76				90	72	82			
" 9	81	65	75	11.		5.	89	70	78			
" 10	72	71	72				93	73	81			
" 11	71	67	68	39.	23.	27.	96	72	83			
" 12	77	60	69				87	72	78			
" 13	83	60	70	32.	19.	25.	73	67	73			
" 14	74	57	71				71	56	64			
" 15	83	61	71				79	67	70			
" 16	88	70	77				86	70	77			
" 17	82	69	74	83.	71.	77.	90	66	77			
" 18	65	62	64				94	74	83			
" 19	72	59	64				74	73	77			
" 20	71	62	65	95.	86.	91.	94	74	83			
" 21	74	61	66				95	72	84			
" 22	78	67	67				86	71	74			
" 23	79	60	69	98.	96.	97.	78	59	70			
" 24	80	67	73				83	56	70			
" 25	82	54	63				87	62	87			
" 26	69	53	62	97.	100.	98.	80	63	71			
" 27	74	61	66				70	62	67			
" 28	75	53	64				75	53	64			
" 29	71	59	64	100.	100.	100.	77	50	63			
" 30	65	55	60				80	53	65			
" 31	70	46	56				85	57	69			
Sept. 1	74	49	61	100.	100.	100.	76	63	69			
" 2	82	56	68				82	63	72			
" 3	80	58	69	100.	100.	100.	82	62	71			
" 4	81	62	69				85	61	72			
" 5	76	63	69				89	71	79			
" 6	80	61	69	99.	99.	99.	90	68	74			
" 7	84	67	73				87	72	78			
" 8	87	68	77				78	68	72			
" 9	85	67	76				78	68	72			
" 10	87	68	77	100.	100.	100.	82	58	68			
" 11	89	67	77				85	65	73			
" 12	89	70	79				82	68	75			
" 13	90	71	79	100.	100.	100.	70	62	68			
" 14	90	75	81				75	60	65			
" 15	89	74	79				62	47	58			
" 16	89	72	76	100.	100.	100.	68	35	50			
" 17	82	70	75				76	40	53			
" 18	85	69	74				64	47	59			
" 19	84	40	71	100.	100.	100.	70	35	51			
" 20	70	41	67				77	41	56			

slight influence. Our plan, therefore, was to make a study of our data with reference to temperature alone, and find as nearly as possible the temperature constant for each of the stages; then to study the data with reference to humidity and evaporation and ascertain what effects different humidities or different evaporation rates had on the temperature constant. Several statements have already been made to the effect that the influence of humidity and evaporation is too slight to make it necessary to take them into account. It remains now only to present the data upon which this conclusion was based.

It is hardly to be expected that the degree of humidity of the atmosphere or the rate of evaporation could have any effect on the larva, surrounded as it is by the juicy substance of the apple; therefore the data bearing upon the relation of these factors to the rate of larval development have not been brought together; but the data bearing upon their relation to the rate of development of the egg and pupa are summarized in the following tables (47-50). The ranges of temperature are given at the top of the tables and the ranges of humidity or the rate of evaporation in the first column at the left, and then, in their proper places, are inserted the average effective day-degrees of all the individuals whose periods were observed at the respective temperatures and humidities or rates of evaporation.

In the right-hand column are given the average effective day-degrees for the different degrees of humidity or evaporation regardless of temperature; and at the bottom of the tables, the average effective day-degrees for the different temperatures, regardless of humidity or evaporation. The smaller figures, above the numbers indicating the average effective day-degrees, record the number of observations on which the averages are based.

Tables 47-50 show that there is no consistent variation in the average total effective day-degrees corresponding to the different degrees of humidity or rates of evaporation. The variations are rather hit and miss, apparently depending more upon the number of individuals upon which the averages were based than upon any other factor. In all cases where the number of observations on which the averages were based is large, the average effective day-degrees vary only slightly from the total average. Possibly there is some slight indication that incubation proceeds at a greater rate at humidities between 70 and 74 than at higher or lower humidities and at rates of evaporation between 20 and 24 than at lower rates; but we are hardly warranted in basing any definite conclusion on this indication, and if we were, the variations are so slight that for practical purposes they could be disregarded, since the extreme variations where the number of observations from the average are 500 or more would amount to a variation of less than one eighth of a day in the period.

TABLE 47—RELATION OF HUMIDITY TO RATE OF DEVELOPMENT OF EGG
AS SHOWN BY EFFECTIVE DAY-DEGREES

Temp. Humid.	60°-64°	65°-69°	70°-74°	75°-79°	80°-84°	Average
65-69	¹³⁸ 171.2					¹³⁸ 171.2
70-74	⁵³ 153.0	⁸¹ 164.3	²⁵¹ 161.4	¹¹⁴ 161.0	²⁵⁶ 163.4	⁷⁵⁵ 161.7
75-79	¹⁶⁹ 156.3	⁸⁴⁷ 164.5	⁷⁰³ 162.9	²⁷⁵ 160.3	²⁰⁶ 162.7	²²⁰⁰ 162.6
80-84	¹¹¹ 172.0	²³⁷ 159.6	²⁸² 160.8	¹⁵⁹ 162.6	¹³ 175.0	⁸⁰² 162.6
85-89	¹³² 171.3	³⁸ 174.4	⁷⁰ 172.0	⁵² 163.0		²⁹² 170.4
Average	⁵⁹³ 165.6	¹²⁰³ 165.1	¹³⁰⁶ 162.6	⁶⁰⁰ 161.3	⁴⁷⁵ 163.4	⁴¹⁸⁷ 163.3

TABLE 48—RELATION OF EVAPORATION TO RATE OF DEVELOPMENT OF EGG
AS SHOWN BY EFFECTIVE DAY-DEGREES

Temp. Evap.	60°-64°	65°-69°	70°-74°	75°-79°	80°-84°	Average
5-9	³² 150.0	⁸⁵ 160.9	²¹⁷ 160.4			³³⁴ 159.9
10-14	³⁹⁸ 165.8	⁸⁰⁷ 164.4	⁴³¹ 165.8	³⁵³ 161.4		¹⁹⁸⁰ 164.5
15-19	⁷¹ 159.3	³¹¹ 163.1	⁴⁰⁹ 160.8	⁴⁷ 166.5	¹⁸¹ 166.2	¹⁰¹⁹ 162.6
20-24	¹⁰² 172.9		²⁴⁹ 161.3	¹⁷⁷ 157.6	¹¹² 156.0	⁶⁴⁰ 161.2
25-29				²³ 176.2	¹⁸² 165.4	²⁰⁵ 166.6
Average	⁶⁰³ 165.6	¹²⁰³ 163.9	¹³⁰⁶ 162.5	⁶⁰⁰ 161.2	⁴⁷⁵ 163.5	⁴¹⁸⁷ 163.3

TABLE 49—RELATION OF HUMIDITY TO RATE OF DEVELOPMENT OF PUPA
AS SHOWN BY EFFECTIVE DAY-DEGREES

Temp. Humid.	50°-54°	55°-59°	60°-64°	65°-69°	70°-74°	75°-79°	80°-84°	Average
60-64								
65-69		508 238.7			55 237.0		2 254.0	565 238.6
70-74	42 236.2	955 240.9			34 247.2	163 238.3	369 244.4	1663 241.5
75-79				31 236.0	125 248.3	586 242.7	18 239.9	760 243.3
80-84				167 234.7	339 235.0	357 237.3		863 235.9
Average	42 236.2	1463 240.1		198 234.4	553 239.0	1106 240.6	389 244.2	3751 240.1

TABLE 50—RELATION OF EVAPORATION TO RATE OF DEVELOPMENT OF PUPA
AS SHOWN BY EFFECTIVE DAY-DEGREES

Temp. Evap.	50°-54°	55°-59°	65°-69°	70°-74°	75°-79°	80°-84°	Average
5-9	42 236.0	1077 240.2	52 237.9	6 224.1			1177 239.8
10-14		174 243.7	146 233.3	395 236.4	380 238.3		1095 237.8
15-19				70 251.4	480 242.6		550 244.5
20-24		212 237.1		34 241.4	199 239.1	16 239.0	461 238.3
25-29				48 238.7	47 235.0	363 244.5	458 242.9
Average	42 236.0	1463 240.1	108 234.4	553 239.0	1106 240.6	879 244.2	3741 240.1

SPRAY PROGRAM FOR THE CODLING-MOTH

Spray programs heretofore outlined have been based on fixed dates or on time of the fall of the petals. It is better to follow programs of these kinds than to spray hit and miss, but these programs do not take into consideration seasonal variations and variations due to local peculiarities, to altitude, to latitude, or to other circumstances which might have an effect upon temperature.

The following program is based upon the relation of accumulated effective day-degrees to the time of the appearance of the different broods of larvæ. It provides for seven sprays, three for the first brood, two for the second, and two for the third. The table shows the accumulation of effective day-degrees at which the fruit-grower should begin to spray in order that he may complete the work in from one to ten days. This spray program (Table 51), like all others which have been proposed, must be tested thoroughly and proved reliable before it can be accepted as satisfactory.

Too much emphasis can not be placed upon the necessity of applying two sprays for the second brood of larvæ, and of making the first spray for the second brood very thorough. The second brood is much more numerous than the first and comes at a time when the fruit is increasing in size very rapidly; hence, one spray applied at the time when the first larvæ of the second brood enter the fruit will not suffice to check those that enter three or four weeks later. The second and third broods of larvæ overlap, consequently after the second brood begins to enter the fruit larvæ are entering it continuously in large numbers till all the third-brood larvæ have entered, hence the fruit should be well protected during this period.

The first larvæ of the second generation which enter the fruit during July transform and produce the third generation; hence the importance of making the first spray for the second brood (the fourth spray on the program) very thorough so as to destroy as many of the first larvæ of this brood as possible. To reduce the third brood still further the spraying should be supplemented by the destruction of larvæ under bands up to the first of September. Larvæ that leave the fruit after that date will not transform until the following spring, and may be destroyed any time after the season closes.

The seventh spray, or the second spray for the third brood, will not be necessary in case the sixth spray comes late in August. If it should come prior to the 15th of August the seventh spray will be advisable unless the latter part of August should be much cooler than normal.

TABLE 51.—SPRAY PROGRAM

Brood of larvae spray	Average normal daily effective day- degrees†	Accumulation of effective day-degrees when spraying should begin, to be completed in:									
		1 day	2 days	3 days	4 days	5 days	6 days	7 days	8 days	9 days	10 days
1st*	16	534	518	502	486	470	454	438	422	406	390
2d	20	770	750	730	710	690	670	650	630	610	590
3d	26	1524	1498	1472	1446	1420	1394	1368	1342	1316	1290
4th	27	2023	1996	1969	1942	1915	1888	1861	1834	1807	1780
5th	27	2523	2496	2469	2442	2415	2388	2361	2334	2307	2280
6th	23	3027	3004	2981	2958	2935	2912	2889	2866	2843	2810
7th											

* The application of the first spray for the codling-moth should begin when the petals are about two-thirds off. The time of full bloom is not dependent upon effective day-degrees as defined in the preceding pages, and hence the time of the application of the first spray can not be determined by the accumulation of effective day-degrees.

† The figures in this column are the approximate number of effective day-degrees that are accumulating daily at the time when the various sprays are applied.



STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION
DIVISION OF THE
NATURAL HISTORY SURVEY
STEPHEN A. FORBES, Chief

Vol. XIV.

BULLETIN

Article VIII.

FIRST REPORT ON A
FORESTRY SURVEY
OF ILLINOIS

BY

ROBERT B. MILLER



PRINTED BY AUTHORITY OF THE STATE OF ILLINOIS

URBANA, ILLINOIS

March, 1923

STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION
A. M. SHELTON, *Director*

BOARD OF
NATURAL RESOURCES AND CONSERVATION

A. M. SHELTON, *Chairman*

WILLIAM TRELEASE, *Biology*
JOHN M. COULTER, *Forestry*
EDSON S. BASTIN, *Geology*
WILLIAM A. NOYES, *Chemistry*

JOHN W. ALVORD, *Engineering*
KENDRIC C. BABCOCK, *Representing the*
President of the University of Illinois

THE NATURAL HISTORY SURVEY DIVISION

STEPHEN A. FORBES, *Chief*

CONTENTS

	PAGE
Introduction	291
Acknowledgments	295
I. Land classification	296
The forest:	
History	297
Forest types	298
Detailed exhibit of stand of types by counties for area surveyed, and per cent of it wooded.....	300
Important trees and their main uses:	
Hardwoods	302
Tabulated data obtained by a study of types of upland and bottomland timber	313-317
Annual cut in board feet	317
Physiographic features:	
Topography	318
Drainage	319
Geology	320
Soil types	324
Climate	327
II. Milling and logging operations and wood-using industries in South- ern Illinois	327
List of mills, with location and output	330
The veneer industry	331
Manufacturers in the region, and products	332
Necessity for a local supply of "softwoods" for veneer purposes	333
Charcoal-making: Processes and yields.....	334
Ties and mine timbers:	
Railroad cross-ties	335
Specifications, grades and sizes, species	335
Wood preservation and tie-treating plants in Illinois	337
Timber used in coal mines	340
III. Forest problems:	
Fires	342
Direct effects of fires	342
Injury to reproduction	343
Injury to the soil.....	343
Injury to productive power of the forest	344
Effect of severe burning upon young stands	346
Erosion	346
Grazing	347
IV. Forest policy and management	348
The upland timber belt	348
Outline of proposed fire-protection system for upland timber belt	348
The so-called farm wood-lots	349
The overflow bottomlands	350
V. Volume and growth studies	350
Stem analysis	351
Bibliography	354
Appendix:	
Volume tables for leading species, and taper and growth tables and graphs for white and black oak	357

ARTICLE VIII.—*First Report on a Forestry Survey of Illinois.* By
ROBERT B. MILLER, Forester, Natural History Survey.

INTRODUCTION

The forest area in Illinois to which this report applies is bounded by the Mississippi River on the west and the third principal meridian on the east, and extends in a north and south direction from Thebes, in Alexander county, to Chester, in Randolph county. It comprises all of Jackson county and portions of Union, Alexander, Pulaski, and Randolph counties, a total of 697,286 acres. It forms the western part of the Ozark highlands of southern Illinois (Colyer, '22), a region which extends across the state for 75 miles, with an average width of about 25 miles, from the mouth of the Big Muddy on the Mississippi to Shawneetown on the Ohio. The highest elevation of this highland belt is "Williams Mountain" (1,065 feet), in the northeastern part of Pope county, Bald Knob, in Union county, coming next, with an elevation of 1,025 feet. The difference of elevation between the crest and the base of the Ozarks is often 500 to 600 feet. A relief map of the state shows that this entire highland region includes the southern parts of Jackson, Williamson, Saline, and Gallatin counties, almost the whole of Union, Johnson, Pope, Hardin, and Alexander counties, and a part of Massac county. Reports of the State Soil Survey for these ten counties show that the amount of rough and hilly land ranges from 23 per cent in Gallatin county to 79 per cent in Hardin county. From the topography of these uplands and the lightness of their soils, which are classed either as yellow-gray or light gray silt-loams, it can be seen that the forces of erosion must be at their maximum, so that most of the region is in a mature stage of dissection.

The occupations of the inhabitants are directly related to the topography of the region. The bottoms of the Mississippi, Big Muddy, and Cache rivers make very fertile farming lands, suitable for corn when drained and cleared, while the steeper cleared lands may be used for mixed farming, but are better adapted to wheat than to corn. The narrower bottoms of secondary streams are adapted to the raising of berries, melons, cucumbers, and tomatoes, for the marketing of which there are good transportation facilities. Extensive peach and apple orchards have been developed in some portions of the upland because the higher parts often escape frosts which are destructive on the lower levels. Some of the

uplands, besides having a value for timber growing and stock raising, are underlaid with coal or contain deposits of silicon, ganister, and kaolin. Cliffs of limestone are frequent and furnish fertilizer and building stone, and the chert ledges yield road material.

The western portion of this highland region was chosen as a subject for a preliminary report on forest conditions for the following reasons:

1. It has the most continuous body of timber in the state, and because of its nearness to important wood-using centers is admirably located for continuous forest management.

2. The timber, being largely on uplands, is on cheap land which is poorly adapted to agriculture under ordinary methods of cropping because of high elevation, steep slopes, and a soil which erodes very badly when the protecting forest cover is removed.

3. A very considerable amount of information concerning the region has been accessible to us. The soil map and report on Union county are now in course of preparation by the State Soil Survey, while topographic maps of the Alto Pass, Jonesboro, Carbondale, and Dongola quadrangles are in various stages of preparation by the State Geological Survey, detailed information having been available both on the geology and soils of the region.

4. When the time comes for Illinois to acquire land for state forests, it is believed that this report and the accompanying map will be of service in showing where suitable tracts are located and will give some idea of their nature and value. As Henry S. Graves ('21) points out, the acquisition of public forests by states would furnish examples of the best methods of protecting and handling forests in the regions in which they were established. Thus managed they would also help to strengthen the local wood-using industries by assuring a regular supply of timber and would become real factors in the upbuilding of rural communities.

The total area represented by the map of this region accompanying this report, is 697,286 acres, 522,250 of which are cleared or in pasture and 175,036 acres are woodland. There are 147,636 acres of timber which may be classed as merchantable, 131,217 acres being upland and 16,419 acres bottomland timber. There are 13,299 acres which may be classed as culled forest, which means that the merchantable trees have been removed as the demand came, leaving trees which were defective, of inferior species, or too small for the market. Such lands have a future value if fire is kept out of them for a few years until the slash decays and reproduction has started. There are 14,100 acres classed as saplings, that is, the ground is well covered with trees of sapling and pole sizes, not yet merchantable, but which will have a distinct value within the next ten years if properly protected and handled. Of the entire area covered

by our map, 30.8 per cent is wooded, and that portion west of the Mobile and Ohio Railroad (which forms a rather distinct boundary between the more solid timber and the region of scattered wood-lots to the east) is 45.9 per cent wooded. This region west of the railway is also different in its problems from the region of scattered wood-lots to the east, where the tracts surrounded by roads can be better protected by their owners against fire.

In the 131,217 acres of upland forest, the main species and the per cent of the stand which they form, are as follows: black oak, 27.6 per cent; white oak, 20.8 per cent; beech, 18.1 per cent; hickory, 14.1 per cent; and tulip-tree, 5.1 per cent. Miscellaneous species, such as maple, black gum, red gum, ash, elm, walnut, and mulberry make up the remainder of the stand. Stand tables compiled for 117 acres at Alto Pass and for 65 acres at Jonesboro, both areas of the upland type, show that on the former area there were standing on an average acre only 33.32 trees of all species 6 inches or more in diameter breast-high; and on the latter area, only 43.65 trees of all species of this size per acre. The average acre at Jonesboro contained 1,948 board feet and at Alto Pass 2,362 board feet, while a combination of the figures for 182.3 acres gave 2,228 board feet, or 8.68 cords per acre, counting 90 cubic feet as equivalent to one cord. These figures of the number of trees per acre, when compared with those for very similar sites which we find in published yield-tables, show that these forests are decidedly understocked, because of fires and culling. The culling out of the larger specimens has its justification in meeting the demands of the market for certain species as they become valuable, and does not impair the usefulness of a forest as a protection against erosion; but the prevalence of fires is entirely unjustifiable on any grounds, and owners should be given assistance and encouragement in controlling them along the lines discussed under "Policy and Management."

Our map shows 16,419 acres of bottomland forests; but not much time was spent on the bottoms because only that portion of them needs to be considered which is incapable of drainage or which has an impervious subsoil. We listed 2,894 acres of 1B* cypress on these lands and some No. 4* cypress running as high as 13,000 board feet per acre; but cypress is mostly in small patches or mixed with bottomland hardwoods. Owing to the number of drainage ditches, cypress will not long rank as a commercial species, since when cut on drained land its place is taken by gums, willow, soft maple, and cottonwood, called locally "softwoods." This latter variety of forest, when situated on land which can not be devoted to agriculture for some years because of periodical floods, should

*See pages 298, 299.

not for that reason be overlooked, since it is valuable for the manufacture of veneers, and of charcoal for gunpowder, and willow and cottonwood are used for soda pulp manufacture. Where another crop of this timber can be raised on the land before it is needed for farming, it should certainly be utilized for timber-growing, since it is less subject than the upland to damage by fires, and makes more rapid growth.

From the most reliable information obtainable, we estimate the annual cut of timber in the region covered by our map at about 20,000,000 board feet. The veneer industry uses a large amount of the local supply for veneers for baskets and crates and hampers for fruit and vegetables; the railway companies secure large numbers of railroad ties from species along their rights-of-way which may be used directly or are sent for treatment to the wood-preserving plants in that region; stationary and portable mills saw out lumber, cross-ties, car stock, and mine ties; while a very large amount of round timber purchased by contractors is shipped to mines in the counties farther east in the form of props, legs, and cross bars as well as hewed motor and mine ties. The present supply is coming from woods which if not practically destroyed in many cases by cutting and fires, are at best left with too few or too small trees to replace, by their annual growth, the volume removed by cutting. Even though some of these forests are of poor quality, they represent a resource which if properly developed will contribute very largely to the prosperity of the individual owner and of the community. Development lies along the line of their protection from fire and a handling which will improve their composition and the quantity and quality of their product. Maintenance of a supply of local timber such that the mills of the region will not be forced to move to other sources of supply, as to Arkansas and Missouri, and a development of new industries which will make a market for such species as cottonwood and willow, are measures of a constructive forestry policy. While stressing better protection and the handling of existing stands, we do not intend to underestimate in any degree the importance of a restoration of deforested and waste lands to productiveness by planting them when such a measure is necessary.

The main problem in this region is the prevention of forest fires. Our investigations show that fires are the chief cause in reducing the number of trees far below what should stand on an average acre of upland forest, and are therefore chiefly responsible for the reduction in the volume per acre and in the amount of wood which accrues each year by growth. Some sample plots show that at least 70 per cent of the reproduction and young growth is killed by fire. This thinning out of the stand places the trees too far apart for adequate natural pruning and admits so much light that grass and weeds come in, hindering the reproduction of the better species of trees and further increasing the fire danger.

A comparison of the present area of the upland forest at Alto Pass with soil and topographic maps of the same area shows that a large per cent of the forest is on the yellow silt loam along streams, where woods are needed to protect the banks and prevent erosion, and that clearing has about reached the limit of safety for the ultimate good of such lands. The increase, year after year, in some of the southern counties, of lands once farmed and now abandoned, shows that areas hewed out on the slope or the top of a ridge are not adapted to permanent agriculture, while grazing them will undoubtedly result in erosion and the formation of gullies. More intensive cultivation of land already cleared is a better agricultural policy than the further clearing of woodland areas of this description.

The Mobile and Ohio Railroad runs from Sparta to Cairo through this region and divides it into two parts—a western, embracing most of the upland timber which is in more or less solid blocks; and an eastern, which is also rough and hilly but contains timber in wood-lots interspersed with farms and orchards. The Missouri Pacific Railway, from Chester to Cairo, traverses the bottomland on its western edge. It is paralleled from Gorham south by a branch of the Illinois Central, while the main line of the Illinois Central from Chicago to Cairo cuts through its eastern side. One of the main auto roads running north and south, the "Egyptian Trail," is being built through it, while other roads, hilly but quite passable, connect Anna and Jonesboro with Cape Girardeau, Mo., and other points on the Mississippi. The roads in the back country shown on the U. S. topographic sheets as dotted lines can be easily traversed in summer with a light car or a buggy, since they usually wind up some rocky stream bed, or along the tops of the ridges. Where they cross wooded country the best mode of travel is on horseback or on foot, since in this way one can secure from high points the best idea of the country.

ACKNOWLEDGMENTS

We are particularly indebted to Dr. R. S. Smith, of the State Soil Survey, for base maps of many of the counties, without which rapid covering of this territory would have been impossible; also to the chief and members of the soil survey party working on the Union county soil report, for information about the soil types in advance of publication of the report. Our sincere thanks are also due the Director of the United States Geological Survey for woodland sheets of the Dongola and Alto Pass quadrangles and for the Carbondale topographic sheet, and to Mr. J. A. Duck, chief of the topographic survey party in that region, for valuable assistance. The woodland sheets published by the State Geological Survey have been freely used, and have been of very great assistance as accurate base maps and for timber location; and Professor T. E. Savage and Mr. Frank Krey, of the Survey staff, have generously furnished us

with information on the geology of the region as a whole, and on specific areas—such as the Jonesboro and Dongola quadrangles.

I. Land Classification

Land is classified by the county assessors as improved or unimproved, the latter including woods and pastures. A brief statement of conditions for the three main counties embraced in this report is as follows:

<i>County</i>	<i>Improved land</i>	<i>Unimproved land</i>
Alexander	63,806 acres	73,163 acres
Jackson	224,703 acres	155,894 acres
Union	159,901 acres	98,019 acres

The average assessed value of land (which is half the market value) varies from \$2.04 to \$4.23 per acre for the unimproved and from \$9.24 to \$28.88 for the improved lands. These figures are given to show that there is a decidedly large acreage of unimproved land in these three counties—about 327,000 acres—and that its valuation, even at \$4.23 per acre, is not so high as to discourage its purchase by public or private owners interested in the practice of forestry. In some of these southern counties where bottomland is assessed at \$100 per acre its use for forestry purposes is of course out of the question.

For our purpose, we may classify the land under three heads: (1) cleared farm lands, (2) woodlands, and (3) absolute forest lands. By cleared land we mean that which was once cleared, even if it is now growing up to bushes. If reproduction on this is satisfactory, it is classed under saplings. By absolute forest land is meant, as ordinarily defined, "land fit only for forest growth." Since this would greatly restrict the area for forestry in this area, we prefer to say that absolute forest land is that which, on account of excessive slope, rockiness, poor drainage, or other features, will grow a forest crop more profitably than any other. Under it would come gullied land whose reclamation by farming methods would be excessively costly, bottomland which can not be successfully drained, and bare rock cliffs. The area of the last is insignificant.

The distinction between farm and absolute forest land is outside the present discussion, requiring an economic survey of some limited area typical of conditions in a much larger one, in which all the factors of cost of different crops, markets, and transportation conditions, should be considered by a forester who has specialized in economics; and such a survey is contemplated by the Natural History Survey as a part of its forestry program. The most reliable data to be obtained by soil specialists, agronomists, and foresters should form the basis of such an investigation and the results should go far to settle the best uses of our untitled lands.

For our present purposes, land classification and utilization may be covered by the questions: (1) Is the land being profitably farmed now?

(2) Is it reasonably certain that it will be profitably farmed during the time required to grow a commercial forest on that site? If that presumption is not reasonable, then that area *belongs in forest* and should *stay in forest*.*

This would temporarily dispose of any questions as to our gullied lands or wet undrained bottomlands.

Of the entire area mapped, 30.8% is wooded; of that east of the Mobile and Ohio Railroad 16.1% is wooded; while west of the same tracks the woodland area rises to 45.9%. The western upland region, with its high per cent of wooded area in rather large tracts, surrounded by passable roads, thus forms a distinct unit in any plan of management or protection, being the most important as a source of revenue and as a protection forest. The Mississippi bottoms are destined to be brought under cultivation in time; and much of this land is, in fact, already included in organized drainage projects and is being profitably farmed. This 129,846 acres of bottomland can therefore be disregarded excepting those parts of it which can not be drained, and these we have not attempted to distinguish. The classification of upland and bottomland timber types, with their acreages, will be found under the head of "Forest Types," pp. 298 and 299.

THE FOREST HISTORY

Originally the entire area was covered by a dense forest. On the uplands white and black oaks predominated, mixed with such other species as hickory, beech, black gum, red gum, hard maple, tulip-tree (commonly called yellow poplar) and cucumber-tree, these original forests averaging well over 8,000 board feet per acre. White oak and tulip-tree were early marketed, the former probably for staves and heading, and the latter for exterior finish or framing material for barns and houses. The best of hickory was cut for wagon material, and this practice of culling out the best species according to the demands of the market has continued to the present time. About 1870, commercial orcharding developed in this general locality because some of the knobs and slopes were found to be usually very free from injury by frost. This made a demand for barrels and baskets, so that a market was afforded for many "soft-woods" (commercial usage) which has continued down to the present, when many of the cheaper species can also be used for veneers. Beech, which at one time was practically unused, was then sought in the ravines and coves because it was found that, when given a preservative treatment, it made a good durable railroad tie. Sycamore, hackberry, and soft maple could also be so used.

*Lovejoy, '19.

Repeated cullings have thus reduced the number of older trees standing upon an acre and repeated fires have prevented young trees from filling up the blanks. As a result, the present stands show an average of only 33 to 43.5 trees per acre, although normal yield-tables for such hardwoods made up from fully stocked stands show that at least 130 trees per acre, or four times as many, should be present (see stand tables for sample acres at Alto Pass and Jonesboro, pp. 313, 314). This decrease of growing stock means diminished volumes in such stands and reduced growth per acre.

The depletion of the stands has been stimulated by the excellent marketing and shipping facilities. Four lines of railway traverse this region in a north and south direction—the main line of the Illinois Central from Chicago to Cairo on the eastern side, the Mobile and Ohio through the center of the area, and on the west a branch of the Illinois Central and one of the Missouri Pacific running parallel from Leo Rock to Thebes. The nearness of these railroad lines makes it possible to ship logs, mine props, and railroad ties without hauling them any great distance. Several veneer plants are located on the main line of the Illinois Central and various wood-using industries have been built up at Cairo and Mound City, which, while drawing the bulk of their logs from the Ohio and Mississippi rivers, yet use some local logs.

FOREST TYPES

We have divided the forests of this region into upland and bottom-land types, but no attempt has been made at further division on a basis of site. While we may use the terms beech-maple, oak-hickory, and the like, in distinguishing forests in this region we shall attempt no close definition of their limits as it would be almost an impossibility to trace them. Writing of the forests of Alexander county, Ill., Dr. George D. Fuller ('22) very pertinently says: "The various types and their subdivisions merge into one another by gradations that are often almost imperceptible, presenting degrees of difference that are quite impossible to discuss or map in a preliminary survey like the present study."

Of the upland types we have distinguished the following:

Culled forest—text symbol, Cull.*—Stands from which merchantable trees have been entirely removed, with occasional weed, or defective, trees left. There are 12,584 acres of this type.

Saplings—text symbol, Sap.—Stands in which the trees are not large enough to be merchantable, including growth coming in on old fields or after a previous cutting. This type has a distinct future value. There are 13,489 acres of this type.

*The symbols given in this connection are used only in the text and tables, our map of the region being self-explanatory.

No. 1—text symbol, 1.—Stands from which the more desirable species and best trees have been cut. There are 118,247 acres of this kind of timber mapped, with an average of 1,000 and a maximum of 2,000 board feet per acre.

No. 2—text symbol, 2.—Stands yielding from 2,000 to 5,000 board feet per acre, with an average of 3,750 board feet. These are generally very fair stands of desirable species where light cullings have been made. Our map shows 12,584 acres in this division.

No. 3—text symbol, 3.—Stands which will run from 5,000 to 10,000 board feet per acre; probably typical of the original stands, with an average of 7,500 board feet. No culling, or at most very light culling has taken place. The area is only 368 acres.

No. 4—text symbol, 4.—Stands which are exceptionally good, where the trees are large and are generally on good agricultural soil, with a yield of over 10,000 board feet per acre. Only 18 acres were classed as of this type.

Total of the upland types, 157,290 acres.

For the bottomland types the same designations as to yield are used as are applied to uplands except that each is followed by the letter B.

Culled forest—text symbol, Cull B.....	715 acres
Saplings—text symbol, Sap. B.....	612 acres
No. 1—text symbol, 1B.....	12,473 acres
No. 2—text symbol, 2B.....	937 acres

The foregoing are the straight bottomland symbols, but when strictly bottomland type and hardwoods are mixed with cypress we have the following:

1B cypress	2,894 acres
2B cypress	115 acres

Total of the bottomlands types, 17,746 acres.

The strictly bottomland type as distinguished from the upland type is characterized by a greater number of species. These are pin, white, swamp white, red, and bur oaks, elm, sweet gum, hickory, locust, black walnut, and tulip-tree. Where cypress is found there is usually tupelo, red gum, and soft maple, with some willow and cottonwood.

The composition of the upland type is well shown by the two stand-tables on pages 33 and 34, compiled from strip surveys representing 117.18 acres at Alto Pass, and 65.14 near Jonesboro. The cruising was done by a three-man party, one man running the line with a staff compass and tallying, and two others, known as caliper men or cruisers, each taking a strip 33 feet in width on one side of the chain, calling out the species,

diameter breast-high, and merchantable heights of all trees 6 inches in diameter and over on his side of the chain. Topographic maps giving the location of ravines and ridges are very useful in cruising by this method, and in very rough country the steel tape may be dispensed with. When the party has progressed ten chains (660 feet) in this manner and with this width of strip (66 feet) they have covered one acre.

The area cruised out of a section of 640 acres will of course depend on the distance between the cruise lines. When they are run at intervals of 20 chains (a quarter of a mile) they give a 5 per cent estimate, and when at intervals of 10 chains (an eighth of a mile, or 660 feet), a 10 per cent estimate. In addition to recording the apparent effect of fires upon young growth, plots a square rod in size were measured off at intervals of 10 chains in order to estimate reproduction. This plotting is easily and quickly done by the use of a 50-foot cloth tape, taking 16½ feet on the center cruise-line and having the men form a square with the cloth tape 16½ feet on the other three sides. All sprouts and seedlings within the square are then counted and tallied, with a designation as to height. This represents reproduction on 1/160 of an acre.

DETAILED EXHIBIT OF STAND OF TYPES, BY COUNTIES, FOR AREA
SURVEYED, AND PER CENT OF IT WOODED

Pulaski County

Type*	Acres
1B cypress	2,894
2B cypress	115
Cull B.	194
No. 1.	616
No. 2.	26
No. 2B.	50
Sap. B.	45
Total.	3,940

Total area of county surveyed was 35,000 acres, 11.2% of it wooded.

Randolph County

Type	Acres
No. 1.	10,795
No. 2.	400
Sap.	1,240
Cull.	60
No. 1B.	655
No. 2B.	400
Total.	13,550

Total area of county surveyed was 26,427 acres, 51.2% of it wooded.

*For definition of type symbols see pp. 298, 299.

Union County

	Timber west of M. & O. R. R. to Mississippi Bluffs	Timber east of M. & O. R. R.	Total area of timber in types
Type	Acres	Acres	Acres
No. 1.....	23,564	7,928	31,492
No. 2.....	6,762	1,672	8,434
Cull.....	1,853	66	1,919
Sap.....	1,179	565	1,744
No. 3.....	.....	368	368
No. 4.....	.....	18	18
	33,538	10,617	43,975

Total area of county surveyed was 151,261 acres, 29% of it wooded.

Alexander County

	Timber west of M. & O. R. R. to Mississippi Bluffs	Timber east of M. & O. R. R.	Total area of timber types
Type	Acres	Acres	Acres
No. 1B.....	214	855	1,069
No. 2B.....	.....	22	22
No. 1.....	21,083	1,567	22,650
No. 2.....	1,583	200	1,783
Cull.....	6,816	190	7,006
Sap.....	36	256	292
Cull B.....	.....	521	521
Sap. B.....	.....	90	90
	29,732	3,701	33,433

Total area of county surveyed was 114,193 acres, 29.2% of it wooded.

Jackson County

	Timber west of M. & O. R. R. to Mississippi Bluffs	Timber east of M. & O. R. R.	Total area of timber types
Type	Acres	Acres	Acres
No. 1.....	41,307	10,427	51,734
No. 2.....	1,595	346	1,941
Cull.....	1,202	60	1,262
Sap.....	1,059	9,154	10,213
No. 1B.....	.....	10,749	10,749
Sap. B.....	.....	477	477
No. 2B.....	.....	465	465
	45,163	31,678	76,841

Timber on
Fountain Bluff

Type	Acres
Cull.....	2,337
No. 1.....	960
	3,297
	76,841

Total.....80,138

* Total area of county surveyed, exclusive of bottomland, was 275,559 acres, 29% of it wooded.

SUMMARY OF FOREGOING DETAIL

TOTAL OF TIMBER BY TYPES AS SHOWN ON OUR MAP OF THE REGION

Types	Acres
2B cypress.....	115
No. 1.....	118,247
No. 2.....	12,584
Cull.....	12,584
Sap.....	13,489
No. 1B.....	12,473
No. 2B.....	937
1B cypress.....	2,894
No. 3.....	368
No. 4.....	18
Sap. B.....	612
Cull B.....	715
Total.....	175,036

IMPORTANT TREES AND THEIR MAIN USES

*Hardwoods**

List of white oaks:—

Quercus alba. White oak.*Quercus platanooides*. Swamp white oak.*Quercus macrocarpa*. Bur oak.*Quercus michauxii*. Cow oak.*Quercus minor*. Post oak.

The "White Oaks."—This group includes not only *Quercus alba* but swamp white oak, bur oak, cow oak, and post oak. The main distinction between the two groups of oaks, white and black, lies in the structure of the wood. In white oaks the large spring pores are plugged with a growth from the surrounding parenchyma cells known as tyloses, while the pores in the summer wood are thin-walled and angular. In the black or red oak group the walls of the spring pores are without tyloses, while the summer pores are thick-walled and more nearly circular in cross-section. The white oak (*Q. alba*) is marketed for saw and veneer logs, wagon stock, tight cooperage, interior finish, furniture, and flooring, the poorer grades going into railroad ties, mine timbers, and cross bars. Swamp white, bur oak, and cow oak are marketed in the white oak group, as their wood is of equal quality and durability. Post oak is used largely for posts and mine timbers. It grows on flat ridge-tops known as "post oak flats," and on light gray silt-loam underlaid by tight clay which characterizes some of the poorer lands of the Ozark region. Black-jack

*According to the use of the term by foresters, a hardwood tree is one that has broad leaves, while the term softwood refers only to a needle-leaved tree, or conifer. As used in veneer and allied trades in this region and by woodsmen and lumbermen generally, the term softwood includes such trees as cottonwood, soft maple, sycamore, gums, and other bottomland species remaining after oak and cypress have been cut. As the forester uses the term, the only softwoods in southern Illinois are shortleaf pine, cypress, and red cedar.

(*Q. marilandica*) is another inferior oak which comes in thickly on burned lands.

List of "black oaks":—

Quercus rubra. Red oak (sometimes called sour oak).

Quercus velutina. Black oak, yellow oak.

Quercus palustris. Pin oak, water oak.

Quercus coccinea. Scarlet oak.

Quercus falcata. Spanish oak (around Vienna).

Quercus imbricaria. Shingle oak (leaves resembling those of willow oak).

Black Oak or Red Oak Group.—The main trees coming under the red oak group, as it is generally called, are red oak, black oak, pin oak, scarlet oak, Spanish oak (around Vienna), and shingle oak.

These oaks go into the furniture and veneer trade; but with the development of wood preservation it has been found that red oak ties can be made as durable as white oak by the use of creosote or zinc chloride. The pin oak (*Q. palustris*), often called water oak, and the shingle oak (*Q. imbricaria*) are sold as black oaks, although the latter is more properly classed with the willow oaks.

Liriodendron tulipifera. *Yellow Poplar*. *Tulip-tree*.—The tulip-tree is more likely to be found in the cooler ravines and small coves, along with beech and white oak, or in small undrained depressions where the seed finds proper light and germinating conditions, as it is intolerant of shade. Seedlings of this tree are also found in old fields which are growing up to sassafras and persimmon, where the soil has started to erode along the ravines. It makes an ideal wood for all kinds of exterior house-finish, such as siding, porch columns, and cornice, taking paint and resisting the weather remarkably well. In this region it is more likely to be used for veneers for baskets or sawed into rough lumber. The wood works easily and is sought by cabinet-makers for this reason. It can be distinguished from the cucumber-tree by the fact that its vessels are of the pitted variety, while those of the cucumber-tree are scalariform—a character to be made out only by the use of a compound microscope on the tangential surface of the wood. It is a tree of rapid growth and should be encouraged wherever there are seed trees and favorable conditions.

Fagus grandifolia. *Beech*.—This is a tree which does well in shade, and hence grows on the northern slopes, along with hard maple. We could not find that it discriminates between limestone soils and cherty soils, as it is found on both. The beech has a heavy, strong wood, resembling birch and hard maple, but it can be distinguished from either of them by the fact that the pith rays are quite distinct and about twice as wide as the diameter of the largest spring pores. Within the last few

years the woods of this region have been culled for beech, since, when sent to the treating plant, it makes a good railway tie; and it is also sawed for car stock and switch ties. Heavy cutting makes light and moisture conditions unfavorable for beech, hence with rare exceptions it reproduces largely by root suckers, and is generally replaced in the new stand by more xerophytic species, such as black oak and hickory. There is still considerable beech around Alto Pass in woods which have not been burned over, because of moister conditions of the leaf litter.

Hickories. (*Genus Hicoria.*)—While there are several species of hickory in this region the classification of some of which gives trouble to the botanist, no distinction is made in the lumber.

Hicoria ovata. *Shagbark or Shellbark Hickory.*—This tree is easily recognized by the bark, which exfoliates in long strips. The leaflets are three to five, ovate to obovate in shape, hairy beneath when they unfold and usually until maturity, but sometimes almost glabrous. The nut is small and sweet—one of the best of the hickory-nuts coming into our markets. Hickory is strong, but not durable in the ground, and is used principally for carriage and wagon stock, handles, and sucker rods, while young saplings are used for hoop-poles and rustic furniture. The old distinction in the trade by which only the white sap-wood was used for wagon parts or spokes has disappeared, since the brown heartwood is normally just as strong as the sap-wood. Hickory sprouts vigorously when the younger trees are cut and its sprouts are very fire-resistant, so that it is forming a larger and larger proportion of our southern Illinois upland forests.

Hicoria laciniosa. *Big Shellbark Hickory.*—This hickory, also known as the big scaly bark hickory, is found in the bottoms, often associated with the shellbark hickory. The nuts are very much larger and harder to crack than those of the latter species. Its wood has similar properties and its uses are the same as those of the shellbark, although its bark, according to Professor Trelease, is usually less shaggy.

Hicoria pecan. *Pecan Hickory.*—This species belongs to the water hickories, having from 9-17 leaflets, and buds which resemble those of the bitternut hickory. It is found on bottomlands subject to overflow, and in some parts of the region under discussion specimens are left standing in the fields on account of the value of their crop of nuts. When other trees in the woods are removed from around pecan the crown spreads, making it more valuable for nut production. Its wood is the poorest of all the hickories.

Hicoria minima. *Bitternut Hickory.*—This is also one of the water hickories and can usually be identified by the more numerous and narrower leaflets, and by the twigs and buds—both of which are sometimes

coated with a glandular yellow pubescence. The fruit sometimes has prominent sutures often slightly toothed, which split to a little below the middle of the nut. The kernel is bitter and not edible. It usually grows in moist situations along streams. The wood is white and the bark smooth.

Hicoria glabra. *Pignut Hickory*.—According to Trelease ('96) the typical eastern pignut hickory (*Carya porcina*), with nearly indehiscent husk, does not occur west of the Alleghanies, being replaced by the variety *odorata*. Dr. Trelease divides the species *glabra* into three varieties: *odorata*, the bark of which resembles that of the elm, being deeply ridged but not shaggy, with often nearly red twigs; *villosa*, a hill form with hairy twigs, with a bark resembling that of the persimmon tree; and *microcarpa*, which has a bark often as shaggy as the shagbark, and a nut usually gray to whitish, angled, and having a sweet kernel. The varieties *odorata* and *microcarpa* shade into each other, making their separation difficult. The wood of all the so-called pignut hickories differs little in character and may be used for wagon stock, spokes, handles, etc. In southern Illinois it is often sawed into pieces about 6 feet square, long known as trolley poles for mines. It is also used for sprags and mine ties.

Morus rubra. *Red Mulberry*.—The red mulberry has a very durable wood and is classed in this particular with such woods as chestnut, catalpa, and sassafras. Mulberry grows on small, rich bottoms, and farmers when making a timber sale usually reserve the mulberry because of its value for fence posts, although we have seen it among mine timbers and in charcoal wood. The heartwood is orange to yellowish brown, becoming russet-brown upon exposure to the weather. The sap-wood is thin and nearly white. It somewhat resembles the wood of Osage orange, which it approaches in durability.

Liquidambar styraciflua. *Red Gum*.—This is a species which improved methods of seasoning and drying have converted into a valuable wood for interior finish, all kinds of furniture, cooperage, and thin veneers suitable for crates and berry boxes. In the trade it is known as "satin walnut" owing to the fineness of its texture, the best grades going into veneer logs for furniture and interior finish. The wood is close-grained and tough, the color reddish brown, often with irregular dark streaks which make it valuable for doors and paneling. The tree is usually recognized by the star-shaped leaf and by its peculiar pronged fruits on long stalks.

Nyssa aquatica. *Tupelo*.—This is one of the most characteristic trees of the Mississippi and Cache river bottoms, where it is associated with such trees as the red gum, cypress, swamp white oak, and black gum, *Nyssa sylvatica*. There is very little distinction in color between the heartwood and sap-wood, although the former is sometimes

cream-colored and is always the more durable. Former difficulties in seasoning this wood have been overcome, so that now it makes a fairly good lumber for floor mouldings, wagon-box boards, furniture, and veneer and interior finish. Preservative treatment makes it valuable for railroad ties and it is also a good wood for paper pulp and charcoal for gunpowder. It is sometimes sold in Europe under the name of bay poplar.

Nyssa sylvatica. *Black Gum.*—This tree is readily recognized by the fact that its leaves turn red or scarlet earlier than those of any other species, and that its branches come out almost at right angles to the stem. Its associates are about the same as those of the tupelo and its uses are similar. Its greatest economic development in Illinois is in its use for the manufacture of egg crates. Its wood is tough and fibrous, making it very hard to split, and it is not durable in the ground unless treated. It is one of the species which comes in great numbers after the logging of cypress, and men who have purchased land for cypress alone have found it becoming valuable on account of the spontaneous growth of black gum, tupelo, and red gum.

Pinus echinata. *Shortleaf Pine.*—It may be a point of interest to botanists to know that there is a stand of shortleaf pine in Illinois on an area commonly referred to as the "pine hills," a ridge above Wolf Lake Station, and paralleling Wolf Lake. This is an old ox-bow lake fed by springs and too deep to be successfully drained. Its location is shown on our map, and one of the plates in this report shows the character of the stand of timber, as well as a log house which is built entirely of shortleaf-pine logs. Judge Karraker, of Jonesboro, tells us that at one time a considerable number of logs were cut on these hills and sawed into boards. The soil is a dry cherty loam and, largely because of fires, the timber is not spreading, although trees of pole size are found in many places. The species can be identified by the needles, which are only about half as long as those of the longleaf pine (*Pinus palustris*), and by the bark, which at maturity is scaly and yellowish red, in very pronounced irregular plates. The nearest out-state location of this species is in Missouri, where it is mixed with hardwoods—mostly white, red, black, and black-jack oak.

Taxodium distichum. *Bald Cypress.*—The bald cypress is of considerable importance in Illinois, occurring in the bottoms of the Mississippi River, near McClure, and in those of the Cache River and the backwaters of the Ohio. In some small areas it occurs in pure stands; and elsewhere it is mixed with gums and other hardwoods. It has been rather closely culled out of the Cache River bottoms, the largest mill sawing cypress in quantities being that of Main Brothers, at Karnak, just outside this region. There is also a mill at Ullin belonging to the Defiance Box Company, of Defiance, Ohio, which saws some cypress into

box boards for crockery crates. Main Brothers use the drainage ditches to float cypress to the mill. This species is easily recognized by its buttressed base and "cypress knees," and by the way in which it towers above the other swamp species. Reproduction is at too low an ebb to produce another crop after the present one is cut, and it is being succeeded by hardwoods.

Juniperus virginiana. Red Cedar.—This tree, of some importance for fence posts, often occurs in pure stands on limestone outcrops along river bluffs and scattered over old pastures. Some 235 stem analyses of this tree were made by the State Natural History Survey in co-operation with the State Department of Agriculture to determine its rate of growth under different conditions. It is injurious in fruit regions because it bears the teleutospore stage of the apple rust in the so-called cedar apples.

Fraxinus americana. White Ash. Gray Ash.—The white ash is found as a bottomland species, associated with such trees as beech, sugar maple, linden, elm, and red oak, preferring openings where there is considerable light. In such situations and with good soil conditions it produces a tall clean stem. The sap-wood is white and the heartwood light brown, the wood being heavy, hard, strong, and elastic. Its main uses are for handles, athletic goods, butter-tubs, car and vehicle stock, automobiles, and implements. Like hickory, the second-growth ash is stronger than old growth, because of the larger proportion of fiber in the summer wood. Clear ash down to a length of four feet can be sold in the form of bolts for handles.

Fraxinus lanceolata. Green Ash.—The green ash is found in wetter situations than white ash, with such trees as white elm, red and silver maple, cottonwood, aspens, linden, and even with cypress. The wood is similar to that of white ash but is inferior in mechanical properties. It succeeds well in plantations, but is subject in this state to injury by the oyster-shell scale.

Acer saccharum. Hard Maple.—This is one of the best of the maples and is commonly associated with beech in the shadier situations, maple being very tolerant of shade. Hard maple is a good wood for furniture, flooring, and interior finish, and makes a good railway tie when treated. It is also suitable for the manufacture of basket veneers, and in this region most of it goes into the market for this purpose. Natural reproduction only takes place in shady, moist situations, such as are found in some of the ravines and small bottoms along streams.

Acer saccharinum. Soft Maple.—This tree occurs in the bottoms along with sycamore, elm, hackberry, and gums, and is used largely for veneers and railroad ties. It grows well from sprouts and should be successfully raised on the coppice system for charcoal. From the silvery appearance of the under side of the leaf it is sometimes called the "silver

maple." The wood is lighter in weight than that of hard maple, but it is a much more rapid grower. Some very large maples were found in bottomlands of this region, one being measured near Ware, growing near the drainage ditch on the Spann tract, which scaled 1,173 board feet.

Differences between Hickories (Hicoria) and Walnuts (Juglans).—Both these genera belong to the family Juglandaceae but can be distinguished by the fact that most of the hickories have nuts with a dehiscent husk splitting into four parts, or, if not, the husk splits part way down by following the ridges or sutures, while the butternut and the walnut must be "hulled" to get at the nuts. Both genera are alike in having compound leaves but different in the fact that the walnut and butternut twigs have a pith with black partitions across them, while the hickories have the ordinary unchambered pith, like the ash.

Juglans nigra. Black Walnut.—Black walnut was found as a scattered tree in the small bottoms of this region and sometimes along pastured ravines on farms, but it reaches its best development in the rich bottomlands of the Mississippi River, where it often occurs with pecan. Walnut is one of our most valuable woods for furniture and veneers, and burl specimens are found which have a grain resembling Circassian walnut. During the war it was sought for gun stocks and aeroplane propellers, and the dark brown heartwood ranks in durability with that of white oak and black locust. Prices for clear logs at the present time run from \$40 to \$150 a thousand feet, f.o.b. cars. Walnut should only be planted on good, rich bottomland, as it does very poorly on yellow silt loam soils.

Juglans cinerea. White Walnut.—An occasional tree of this species is found along streams and banks of ravines, a well-drained gravelly soil being preferred. It is easily distinguished from the black walnut by its grayer bark, by its clammy, almost sessile leaflets, and by the fact that the twigs, buds, and young fruits are covered with a glandular pubescence. The wood in microscopic structure can hardly be distinguished from black walnut, both being classed as "diffuse-porous" woods—that is, there is no marked contrast between the size of spring and summer pores as there is in oaks, ash, and chestnut, which are classed as "ring-porous" hardwoods. The heartwood is a light chestnut-brown, takes a good polish, and is easily worked, so that it is preferred by cabinet makers for the lining and sides of drawers. The nuts are edible and their hull contains a juice which was used by the pioneers for dyeing carpet-rags and clothing.

Magnolia acuminata. Cucumber-tree.—This is one of the magnolias whose range extends northward into the southern Illinois bottomlands. It grows in undrained swamps along with cottonwood, soft maple, tupelo,

and black gum. Its wood can scarcely be distinguished from that of the tulip-tree, and it is used for the same purposes. It can be identified by the long pointed buds and by the fruit, which after the fall of the petals grows from the center of the flower to about the size and in the shape of a small cucumber.

Gleditsia triacanthos. *Honey Locust*.—There are two species of *Gleditsia* in our district, *triacanthos* and *aquatica*, the latter having been found in the woods around Ullin. The first mentioned is the more important commercial species, and is easily recognized by the long-branched thorns on trunk and branches, by the compound leaves, and by the long pods containing hard, dark-brown seeds. The heartwood is classed along with the larch for durability. The species is used for railroad ties, lumber, and charcoal. The wood has a pleasing grain when quarter-sawed, but in durability it does not rank with the black locust.

Tilia americana. *Basswood*.—This is primarily a tree of the river bottoms, where it is associated with elms, hackberry, tulip-tree, and black cherry. The wood is used for wooden-ware, carriage bodies, high-grade trunks and boxes, backing and drawers for furniture, excelsior, and matches. It is light but strong, resembling cottonwood. The genus *Tilia* may be known by the fruit, which consists of two or three nutlets attached to a foliar expansion which assists in scattering the fruit.

Sassafras sassafras.—This is a common tree coming in on old fields, along with persimmon and sumach. It can be identified by the frequently mitten-shaped leaves and the aromatic odor of the inner bark. Its heartwood is brown and very durable, so that it is used for fence posts, cooperage, and boat building. Its roots are used for tea.

Robinia pseudacacia. *Black Locust*.—This tree is quite common in the Ozark region, on slopes above the Ohio River, where it is not attacked by the locust-borer, which is so destructive to pure stands. The wood is strong, and in durability ranks with Osage orange, from which it is not easily distinguished except by the yellower color of the former. It is used for fence posts, telephone poles, and insulator pins, and during the war it was largely utilized for tree nails and for fastening together the parts of wooden ships. The destructiveness of the locust-borer makes it inadvisable to plant this species in southern Illinois, although it is one of the best trees for reclaiming worn-out soils subject to gullying, or for holding blow sand.

Prunus serotina. *Wild Black Cherry*.—Occasional specimens of this tree are found in bottomland forests. It can be recognized by the bark, which is broken up into square plates, and by its fruit, which grows in racemes. The heartwood is of a deep wine-red color, and fine in both grain and texture. It is a valuable cabinet, and an excellent propeller,

wood. It is used for fixtures, backing for cuts, car finish, professional and scientific instruments, furniture, handles, and brushes. It has a pleasing, though not striking, effect when quarter-sawed, and its advantage for furniture lies in the fact that it becomes deep red when varnished without any stain. The wood is durable in the soil.

Celtis occidentalis. Hackberry.—This species, as well as another of the genus (*Celtis mississippiensis*), is found in this region. It can be identified by the leaves, which resemble those of the elm, by the sweet berry, which is largely seed, and by the wart-like excrescences on the bark. Its wood, like that of the elm, is very hard to split. The sap-wood is lemon-yellow, and is hard to season without its splitting. It has no especial merit as lumber, but it is sometimes used for fence boards and is quite commonly made into railroad ties, which have to be treated, however. It can be classed as a bottomland species in this region, growing on land subject to overflow.

Ulmus americana. American Elm. White Elm.—This is the commonest of the elms in southern Illinois, although we also have the slippery elm, (*Ulmus pubescens*) and the winged elm (*Ulmus alata*). *Ulmus serotina* has been reported by Ridgway in the extreme northeast corner of Wayne county, but we have not yet found this species. The white elm is found in meadows where there is considerable seepage and in rich bottomland wood, where it reaches an immense size. One was measured on the Spann tract, in Union county, which was 30 inches in diameter breast-high, and scaled 921 board feet. Its total height was 60 feet and its merchantable length 42 feet. Such trees are used in the manufacture of rotary-cut veneer for baskets and coiled hoops; many of them go into railroad ties.

Red or slippery elm has more pubescent leaves and fruit than white elm, a pinkish, more durable wood, and is used for the same purposes.

The *winged elm* has smaller leaves than other species and the twigs have prominent ridges of cork to which it owes its name.

Populus heterophylla. Swamp Cottonwood. Black Cottonwood. Swamp Poplar.—This tree reaches its best size in river swamps along with red gum, soft maple, cucumber and tulip, attaining diameters of 4 to 6 feet, with very thick deeply ridged bark. According to Deam ('21), of Indiana, the pith of the shoots of this species is orange, while in all of the other cottonwoods it is white. The wood is white, light, and tough, and fairly easy to work, undergoing indentation without splitting. It is a valuable box and crate material, especially for eggs. It is also used for wagon-box boards, veneer, excelsior, paper pulp, and as match stock. Cottonwood thrives best in full sunlight, and for this reason readily gains a footing in old corn fields along the Mississippi River and on sand-bars

with willow and sycamore. It is a prolific sprouter and if there were pulp mills in this region it could be raised profitably by the coppice method on a twenty-year rotation.

The common cottonwood (*Populus deltoides*) may be classed with this species so far as commercial uses are concerned. Both are grown easily from cuttings on overflow lands.

Platanus occidentalis. *Sycamore*.—This tree grows along streams in bottomlands and on sand-bars with willow and cottonwood. It is easily identified, even at a distance, by the green and white spotted bark and by the fruit, known as the buttonball, which is simply a head-like mass of seeds. The wood of sycamore gives a pleasing grain for interior finish when sawed radially, but most of it goes into veneer logs, ordinary dimension lumber, and railroad ties. It is also used for plug-tobacco boxes, and butcher blocks. It grows rapidly on overflow land, both from seedlings and sprouts, and might do well on gullied lands which are not too dry. The largest sycamore in the country is reported by Robert Ridgway ('82), of Olney, Illinois, as growing not far from Mt. Carmel, Ill., in the Wabash bottoms. His measurements show that it had a height of 160 feet, a diameter of 15 feet above the swell of the base, and a spread of 134 feet, making it probably the largest tree of any species east of California.

Salix nigra. *Black Willow*.—The black willow is prevalent along practically the whole course of the Mississippi and this species and the cottonwood are as a rule the first trees to appear on sand-bars and islands. Willow is a very light wood, with the sap-wood whitish to creamy yellow and the heartwood pink to reddish brown. The annual rings of all willows are relatively indistinct, and the wood is quite uniform throughout. Under the microscope black willow can be distinguished from the white by the tendency of the pores in the late wood to form wavy tangential lines. Willow wood is used for lumber, slack cooperage stock, excelsior, charcoal, pulp, artificial limbs, baskets, and fence posts. It is easily raised for revetment work and basketry by the system of pollarding. After cypress is cut in the Cache River bottoms there is a large amount of willow left which on a short rotation would be profitable for charcoal.

Dogwood, *Persimmon*, *Redbud*, *Hop Hornbeam*, and *Blue Beech*.—These trees are of common occurrence but can not be rated as of much economic importance. Dogwood, (*Cornus florida*) forms an under story in some forests and is quite prominent after a cutting-over of the woods. Persimmon (*Diospyros virginiana*) grows in old fields and along roadsides and, with dogwood, might be used for shuttle blocks. Its heartwood is black and known as "American ebony." Redbud or Judas tree (*Cercis canadensis*) with its characteristic purple flowers, is found in bottomland woods along with dogwood, and may be recognized by its

small pods and simple leaves. An occasional hop hornbeam (*Ostrya virginiana*) occurs on slopes along streams, and may be known by its hop-like fruit and by its bark, which exfoliates something like that of a red cedar. Blue beech (*Carpinus caroliniana*) is another small tree, with grayish bark and fluted stem, growing along small streams, and may be recognized by its fruit, which consists of a small nutlet at the base of a three-cleft bract. Both of these latter species may be classed as weed trees and should be removed to give room for more valuable species. Hop hornbeam, on account of its hardness and strength, is used for skids, handspikes, and wooden wedges.

Tabulated data obtained by a study of types of upland and bottomland timber follow.

TABLE 1.—NUMBERS OF TREES OF VARIOUS SPECIES* (UPLAND TYPE) ON AN AVERAGE ACRE
BASED ON 117.18 ACRES, ALTO PASS

D.B.H.† Inches	White oak	Black oak	Beech	Hick- ory	Ash	Maple	Black gum	Tulip- tree	Black walnut	Sassa- fras	Elm	Red gum	Mul- berry	Butter- nut	Totals
6	1.41	1.06	.33	1.33	.17	.15	.02	.09	.07	.02	.21	.05	.01	.....	4.92
7	.83	.72	.18	.73	.12	.08	.02	.09	.03	.....	.06	.01	.....	.....	2.87
8	.86	1.09	.15	.72	.07	.02	.02	.12	.04	.....	.17	.02	.....	.....	3.28
9	.77	1.36	.16	.34	.10	.02	.03	.07	.04	.01	.16	.02	.....	.....	3.08
10	.78	1.40	.15	.48	.05	.02	.06	.11	.03	.01	.11	.....	.....	.01	3.21
11	.53	.90	.19	.27	.03	.03	.04	.11	.03	.01	.05	.02	.....	.....	2.21
12	.49	.90	.16	.39	.03	.02	.08	.07	.....	.02	.02	.02	.....	.01	2.26
13	.50	1.09	.32	.25	.06	.03	.08	.07	.01	.02	.02	.....	.....	.01	2.46
14	.26	.65	.11	.22	.02	.04	.09	.03	.01	.....	.03	.01	.....	.....	1.47
15	.27	.58	.22	.18	.03	.03	1.10	.04	.....	.....	.02	.....	.....	.....	1.19
16	.24	.38	.22	.16	.....	.03	.10	.04	.....	.....	.....	.....	.....	.....	.89
17	.17	.31	.19	.08	.03	.04	.04	.02	.01	.....	.....	.....	.....	.....	.75
18	.12	.15	.27	.13	.....	.01	.04	.03	.....	.....	.....	.....	.....	.....	.69
19	.09	.22	.21	.03	.....	.07	.03	.03	.01	.....	.....	.....	.....	.....	.61
20	.09	.14	.24	.04	.02	.02	.03	.01	.....	.....	.02	.....	.....	.....	.62
21	.12	.11	.24	.03	.01	.02	.03	.03	.02	.....	.....	.01	.....	.....	.38
22	.09	.08	.15	.01	.....	.02	.02	.01	.....	.....	.....	.....	.....	.....	.16
23	.01	.03	.08	.01	.....	.....	.01	.01	.....	.....	.....	.01	.....	.....	.24
24	.04	.02	.13	.02	.....	.01	.02	.....	.....	.....	.....	.....	.....	.....	.12
25	.01	.....	.08	.01	.....	.01	.01	.....	.....	.....	.02	.....	.....	.....	.14
26	.02	.01	.05	.01	.....	.02	.....	.01	.....	.....	.....	.....	.....	.....	.09
27	.01	.06	.....	.....	.....	.....	.01	.....	.01	.....	.....	.....	.....	.....	.05
28	.01	.04	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.01
29	.....	.....	.01	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.07
30	.02	.02	.03	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.05
31	.01	.....	.03	.....	.....	.01	.....	.....	.....	.....	.....	.....	.....	.....	.01
32	.....	.....	.01	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.02
34	.02	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Totals	7.77	11.32	3.91	5.44	.74	.70	.88	.99	.31	.09	.96	.17	.01	.03	33.32

*Used, of course, in the sense of sort or kind. †Abbreviation for diameter breast-high.

TABLE 2.—NUMBERS OF TREES OF VARIOUS SPECIES (UPLAND TYPE) ON AN AVERAGE ACRE
BASED ON 65.14 ACRES, JONESBORO

D.B.H. Inches	White oak	Black oak	Beech	Hick- ory	Ash	Maple	Black gum	Tulip- tree	Black walnut	Elm	Red gum	Bass- wood	Misc.	Totals
6	1.67	1.85	11	1.26	.05	.11	.09	.14		.06	.04		.015	5.40
7	1.09	1.80	.06	.91	.05	.03	.21	.12	.015	.03	.015		.015	4.34
8	1.12	2.06	.20	.90	.09		.03	.11	.015	.05	.05	.03	.015	4.64
9	.88	1.98	.12	.80	.09	.06	.05	.12		.05	.05		.015	4.21
10	.88	1.75	.26	.44	.08		.03	.07		.03	.03		.015	3.65
11	.58	1.38	.17	.37	.06	.015	.14	.14		.03	.03		.03	2.95
12	.57	1.66	.26	.40	.015	.08	.12	.17	.015	.03	.06		.015	3.39
13	.58	1.29	.26	.34	.03	.015	.09	.14	.015	.015	.06			2.84
14	.46	.95	.34	.23	.015	.06	.09	.20		.015	.05		.015	2.43
15	.41	.77	.28	.25	.015	.06	.015	.09			.09		.015	2.00
16	.29	.57	.41	.23	.015	.03	.11	.08		.03	.015			1.78
17	.28	.51	.38	.07		.08	.12	.05			.06			1.55
18	.20	.27	.40	.03		.03	.015	.05			.015			1.01
19	.17	.26	.17	.06		.015	.015	.03					.015	.75
20	.08	.15	.43	.05		.03	.015	.03						.78
21	.09	.11	.23	.03		.015	.015	.015			.015			.52
22	.12	.06	.21	.08			.015							.49
23	.015	.015	.12	.015		.015	.015	.015			.015			.18
24	.05	.015	.12											.21
25	.05		.06				.015							.12
26	.015		.08	.015			.015							.12
27	.015	.015	.05											.08
28			.08											.08
29	.015		.06											.08
30			.015			.015								.03
Totals	9.63	17.45	4.88	6.48	.51	.69	1.26	1.54	.06	.31	.64	.03	.17	43.65

TABLE 3.—ESTIMATE, BY SPECIES, OF BOARD FEET IN STANDS (UPLAND TYPE)
AT BOTH ALTO PASS AND JONESBORO. AVERAGE FOR 182.32 ACRES
(BASED ON DATA IN TABLES 1 AND 2.)

Species	Alto Pass	Jonesboro
Black oak.....	608	592
White oak.....	525	357
Beech.....	415	433
Hickory.....	351	238
Tulip-tree.....	124	97
Maple.....	128	58
Black gum.....	114	75
Ash.....	42	29
Elm.....	40	18
Red gum.....	14	37
Miscellaneous.....	41	14
Totals.....	2,362	1,948

It can be seen from these figures that the species in order of importance are black oak, white oak, beech, and hickory, in both regions, followed by maple, tulip, and black gum. Species of minor importance are ash, elm, and red gum, with a few others such as walnut, mulberry, sassafras, butternut, and hackberry occurring only occasionally.

Combining the results obtained on the 182.32 acres at Alto Pass and Jonesboro, we get the following table of yield by species in board feet, with the per cent of the entire amount that each forms.

TABLE 4

	Board ft. per acre	Per cent of stand
Black oak.....	603	27.6
White oak.....	465	20.8
Beech.....	404	18.1
Hickory.....	316	14.1
Tulip.....	114	5.1
Maple.....	103	4.6
Black gum.....	100	4.5
Ash.....	37	1.6
Elm.....	32	1.4
Walnut.....	23	1.0
Red gum.....	22	1.03
Miscellaneous.....	9	.004
Total.....	2,228	99.834

The stand in cubic feet for the average acre for both tracts combined, by species, is given in the following table.

TABLE 5.—VOLUME BY SPECIES ON AN AVERAGE ACRE, UPLAND TYPE
(BASED ON THE 182.32 ACRES)
TOTAL CONTENTS IN CUBIC FEET

D. B. H. Inches	White oak	Black oak	Hickory	Beech	Tulip-tree
6	6.47	6.09	4.25	5.50	1.21
7	5.47	7.18	5.08	4.08	1.47
8	8.92	10.99	6.64	4.78	1.05
9	9.02	12.52	6.65	1.04	1.62
10	9.90	18.05	8.74	2.30	2.34
11	7.97	17.10	8.76	2.50	5.00
12	8.74	24.76	12.51	3.46	5.94
13	11.07	29.75	8.92	5.63	5.86
14	8.00	24.00	9.46	5.94	8.29
15	12.48	23.78	11.55	7.70	6.57
16	10.14	19.97	12.25	12.71	8.69
17	10.23	20.29	4.68	11.96	6.44
18	11.34	12.07	3.68	14.00	4.16
19	9.23	15.60	2.34	11.42	4.06
20	9.57	10.15	2.56	22.00	4.38
21	8.03	8.80	1.89	15.18	3.28
22	8.66	5.92	2.76	13.14	2.76
23	10.08	.95			
24	4.45	1.75			
25	3.21	1.65			
26	1.97				
27	1.49	4.62			
Totals	176.44	275.99	112.72	143.34	73.12

Grand total, 781.61 cubic feet, or 8.68 cords (90 cu. ft.=1 cord).

TABLE 6.—AVERAGE NUMBER OF BOARD FEET PER ACRE, BOTTOMLAND TYPE
(SYMBOL, NO. 2B*). BASED ON 13.63 ACRES

White oak.....	983	Tulip-tree.....	212
Red gum.....	819	Maple.....	130
Elm.....	477	Black gum.....	109
Sycamore.....	331	Water locust.....	59
Hickory.....	286	Beech.....	56
Black oak.....	235	Walnut.....	30
Ash.....	218		
		Total.....	3,945

N. B.—This bottomland tract of 13.63 acres averaged 33.38 trees per acre, but only those trees were measured whose D. B. H. (diameter breast-high) was 10 inches or more.

*For explanation of symbols see pages 298 and 299.

TABLE 7.—ESTIMATE, BY TYPES, OF TOTAL MERCHANTABLE TIMBER FOR AREA MAPPED

Type*	Acreage	Average board feet per acre	Total board feet for type
UPLAND—131,217 ACRES			
No. 1	118,247	1,000	118,247,000
No. 2	12,584	3,750	47,190,000
No. 3	368	7,500	2,760,000
No. 4	18	12,000	216,000
BOTTOMLAND—16,419 ACRES			
No. 1B	12,473	1,000	12,473,000
No. 2B	937	3,750	3,513,000
1B cypress	2,894	1,000	2,894,000
2B cypress	115	3,750	431,250
Totals	147,636 acres		187,725,000 board feet

*See pages 298 and 299.

ANNUAL CUT IN BOARD FEET

The total cut for the region under discussion and covered by our map is hard to estimate, but it was arrived at in the following manner: The best information obtainable was secured as to the amount of timber used by the veneer plants at Jonesboro, Anna, Cobden, and Dongola—towns which lie at the center of the fruit-producing section; the average railroad tie was figured as containing 33 board feet, and the estimate of timber going into them was based on returns from the various railroad companies as to the number of Illinois-produced ties requisitioned by them in 1921—a total of 913,940. With this number as a basis for estimate* it was assumed that southern Illinois in normal times produced 500,000 and that 300,000 of these at least would come from this region; the amount of sawed lumber was obtained by adding to the actual output of the large stationary mills an assumed amount for the smaller portable mills based on the actual number of days which they might run—which is quite a variable period; and the amount of mine timbers cut in the region and shipped to adjacent counties, upon which there is no definite check, was placed at 4,000,000 board feet. While the individual assignments are necessarily inexact we believe that the total, when made up as follows, is approximately correct.

Veneers	2,000,000	board feet
Cross-ties	10,000,000	" "
Sawed lumber	4,000,000	" "
Mine timbers	4,000,000	" "
Total	20,000,000	board feet

Growth on the average acre, upland type.—Growth per cent on the average acre of upland timber was roughly figured by Pressler's formula,

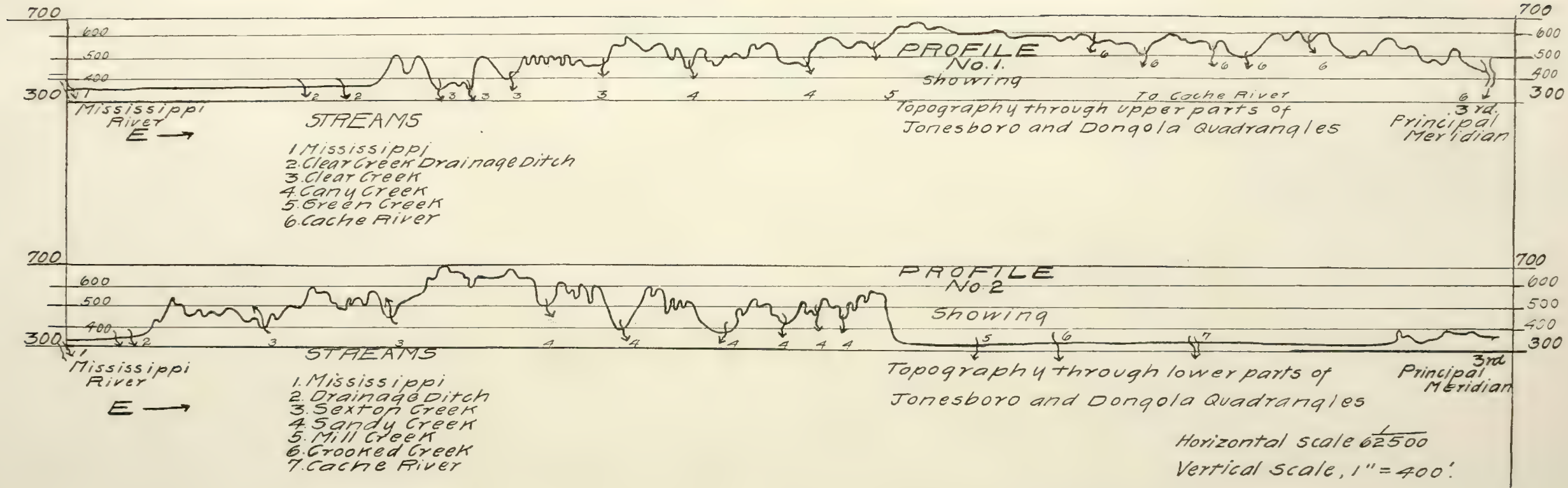
$$\frac{V-v}{V+v} \times \frac{200}{n},$$

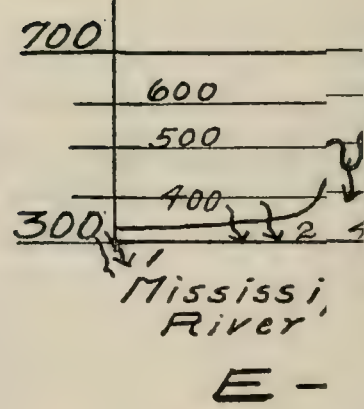
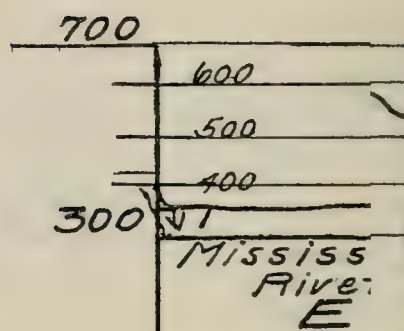
where V equals the present volume on the average acre; and v , its volume n or ten years ago. The merchantable volume at present was computed as 635.53 cubic feet and by figuring from growth tables the volume of each diameter class ten years ago, the total volume at that time was found to be 477.68 cubic feet. Using the formula, we get 2.87 as the growth per cent. This can be applied like simple interest to the present stand, giving the annual increment on the average acre as 18.05 cubic feet, or about $1/5$ of a cord per acre per annum. It would have been more exact to follow Recknagel's method (Recknagel, '16) and to have found a growth per cent for each diameter class, applying this as a percentage to get the increment on the volume of that diameter class and totaling these increments, but according to Chapman ('21) it is not safe to apply such a figure over large areas because the average age, thrift, or other conditions may differ widely from that of the sample area. If, however, this figure were applied to our 131,217 acres of upland merchantable timber it would give an annual increment of about 13,000,000 board feet, assuming that a cubic foot is equivalent to 5.5 board feet.

Whether this growth of about $1/5$ of a cord per acre per year for upland timber is correct or not, it indicates that the annual growth is very low owing to poor stocking, to fires, and to lack of thinning at proper intervals. Baker ('21) cites an example of oak in the sandy region of southern New Jersey where a thinned acre had increased in volume at the rate of about one cord per acre per annum, whereas a check plot near it, not thinned, had only increased 1.1 cords in seven years. An improvement cutting in a stand of 20-year-old mixed hardwoods in the same state resulted in a gain of 9.4 cords per acre in 10 years, or, again, almost a cord per acre per year.

PHYSIOGRAPHIC FEATURES TOPOGRAPHY

The area covered by this report may be divided for convenience into the Mississippi bottomlands and the interior highlands. The Mississippi bottomlands occupy about 18% of the total area of the 697,286 acres, with an average width of four and one-half miles. The relative width at two different places is shown on the Profiles sheet. This part of the area is cut by old river channels and is still subject to local overflows. Natural drainage is poor, the river having an average fall of only six or seven inches to the mile.





The former banks of the Mississippi rise abruptly above the flood-plain to heights of 250 feet in places and this elevation continues across the southern part of the state as a part of the Ozark highlands. There is a north and south axis parallel to the Mississippi culminating near the western part of the Jonesboro quadrangle in bluffs which rise to the height of 700 feet in the north, increase to 880 feet in the middle portion, and decrease again to 700 feet in the southern section. A detached feature of these highlands rises like an island from the Mississippi plain at Fountain Bluff, but elsewhere they are continuous. The east and west axis ends in the chain of heights known as the Shawneetown hills, in Hardin county.

The highest point of our area is some six miles east of the western bluffs at Bald Knob, Union county, where the north and south axis is intersected by the Ozark east and west axis, reaching a height of 1,025 feet. Bald Knob, as already stated, is exceeded in height by Williams Mountain, in Pope county, and, again, by Charles Mound, in Jo Daviess county, but since Bald Knob overlooks the flat flood-plain of the Mississippi, its actual relief is probably much greater than that of the other two points.

Heavy erosion characterizes the western uplands, flanked as they are by the low Mississippi flood-plain. Innumerable short valleys with almost precipitous sides are found, separated by long, very narrow-topped ridges—a form of topography which does not readily lend itself to agriculture.

This minutely dissected upland occurs in a strip averaging five to ten miles in width. East of it the stream valleys are wider, the slopes less precipitous, and the ridge-tops broader, so that the eastern section is well adapted to fruit-growing and general agriculture. In the northeastern part, on the Big Muddy, and in the southeastern section, on the Cache River, wide flood-plains are found.

DRAINAGE

The northern and northwestern part of the region drains into Big Muddy River and its tributaries. Clear Creek, Dutch Creek, Harrison Creek, Horse Creek, and Sexton Creek break through the western bluffs into drainage ditches, emptying into the Mississippi River, while Mill Creek, Lingle Creek, Cooper Creek, and Sandy Creek, in the Jonesboro quadrangle, take their rise in the chert hills, and drain south or southeast into the Cache River. (See the Profiles sheet.) Geologists tell us that the Mississippi was at one time not the master stream, but that some of the streams now draining into it flowed south or southeast.

While the rock strata have in general a slope towards the southeast or east, faults have somewhat broken up the continuity of this slope. The fact that there is such slope can be brought out by comparing elevations

prevailing at the western bluffs with those on the eastern border. At the north the difference in elevation is 300 feet, in the central portion about the same, and in the southern portion 260 feet.

GEOLOGY

A study of Plate LXXI, which was traced directly from the map of the State Geological Survey, will give a very good idea of the geology of this region from Thebes to Chester and west to the third principal meridian—the boundaries of the map. The oldest rocks are placed first in the legend. As we proceed eastward from the Mississippi we encounter successively younger strata, those laid down later in geological history. It should also be kept in mind that this whole region experienced periods of submergence beneath the sea, with a deposition of limestones, sandstones, or shales, depending upon the conditions of the inland waters, these periods of submergence alternating with periods of elevation and subsequent erosion down to base level so that where new layers of sediment were deposited upon the old eroded land forms, there are many examples of what the geologist calls “nonconformity.”

The Ordovician and Silurian, which are the oldest rocks exposed by erosion in Union and Alexander counties, lie like a thin wedge between the Quaternary deposits on the west and the Devonian on the east, running north and south from Fayville to Reynoldsville, and consist mostly of limestones, sandstones, and shales. Since these Pre-Devonian rocks have been fully described by Savage ('08, '09, '10), any attempt at a full description would be out of place here.

The Devonian may be divided into the Lower, Middle, and Upper, and Savage ('20) says that the total thickness of the Devonian rocks in southwestern Illinois is not less than 800 feet. The lowest series of the Devonian is the Helderbergian, represented by Bailey limestone and Backbone limestone. The high bluff facing the Mississippi from Harrison Creek south to Thebes, which one passes in driving from Jonesboro to Reynoldsville along the Cape Girardeau road, may be classed as Helderberg limestone. The Clear Creek chert is a characteristic layer of the Middle Devonian and may be found in two forms: in limestone, as nodules from one inch to two inches in thickness; and as a regular formation constituting the axis of such elevations as Hamburg Hill, Atwood Ridge, Pine Knob, and Dago Hill, extending down through the Jonesboro quadrangle to Tamms. The gravel pit at Tamms is in this formation, and the silicon which is mined at Delta, in Alexander county, is in the Clear Creek chert which has disintegrated. We speak of it because it outcrops in the beds of so many streams, such as Clear Creek, and others, and is an important road-builder and soil-former. Overlying the Clear Creek chert is the Dutch Creek sandstone, so called because it is best

PLATE LXXI



exposed along Dutch Creek, in the southwest corner of Union county. Grand Tower limestone, a layer about 150 feet in thickness, is well exposed in an old quarry a short distance east of Grand Tower, in Jackson county. Lingle limestone and Meisenheimer shale are other representatives of the Middle Devonian. The Upper Devonian is made up of two layers, the Alto Pass formation and the Mountain Glen shale, which is a black shale showing up near Mountain Glen, northwest of Jonesboro.

Above the Devonian is the Mississippian, shown at the extreme right of Plate LXXI, and this is divided into the Lower Mississippian and the Upper Mississippian, the latter being known as the "Chester group." The Springville, or "calico," shale (locally called "ganister"), which is mined in some places to be manufactured into refractory fire-brick, is classed with the Lower Mississippian. The Chester group is made up of limestones, sandstones, and shales, from 700 to 1,200 feet in thickness, and it is partly in this group that the sink-holes in the region of Anna are developed, that entire region being a limestone area. Proceeding upwards, we come to the Pennsylvanian, whose lower layer is the Pottsville sandstone which forms the bluffs at Pomona, all of the northeast corner of the Dongola quadrangle being in fact mostly sandstone where there is considerable poor, gullied land.

Above the Upper Mississippian are the layers of the Carboniferous which contain coal beds developed at Murphysboro, Herrin, and Harrisburg—more thoroughly described in the published geology of the Herrin quadrangle. The coal beds indicate that at intervals there were fresh-water marshes which received an accumulation of plant remains, this coal being formed during what is known as the Carbondale and McLeansboro periods of the Pennsylvanian.

The Permian epoch, which followed the Carboniferous, was one of uplift, faulting, and intrusions of lava, during which the eastern extension of the Ozark highlands occurred, and as a consequence of which we have faults, dikes, and volcanic plugs formed in many of the southern counties. During Cretaceous and Tertiary times, clays, sands, and gravels were laid down, as shown in the lower right-hand corner of Plate LXXI, from Fayville to Tamms. After this came the deposit of sands, gravels, and clays, with glaciation of part of the area during the Quaternary or more recent period.

Glacial and wind action.—As can be seen from Plate LXXI, the southern limit of the Illinoian ice sheet extends across the northwestern corner of our area. According to Savage and Shaw ('12), this last advance of the glaciers southwards covered about 1000 square miles south of the parallel 38 degrees. It left no sign of a terminal moraine, but worked over material deposited previously, brought down rocks, such as quartz, from Canada, and filled up and modified former drainage channels. An example of

PLATE LXXII



LEGEND

-  *Yellow Silt Loam*
-  *Yellow Gray Silt Loam*
-  *Mixed Loam*

Scale 1" = 1 Mile

the latter is found in the fact that at one time the outlet of Big Muddy River into the Mississippi was filled up, forming a large lake called "Big Muddy Lake," which was northeast of this region. Glacial striae, having a general north and south direction, are found just east of this region at Bush, while in another place in the Herrin quadrangle they run south 30 degrees west.

Glacial deposits have been modified or covered up in places by loess, which was blown up by the wind from some of the great outwash plains formed by the glaciers. According to Savage, this may be of two kinds, the deep loess, which has a depth of 50 feet in places, and thin loess about 10 feet in thickness, the two often shading so imperceptibly into each other that they may be considered parts of the same deposit. The thick loess may have been deposited in the forested regions and the thin loess in the undrained lowlands. The true loess weathers with a more or less vertical face, gives a test for lime with acids, and contains the remains of land shells. A good example is found in the cut at Dug Hill, between Jonesboro and Ware, along what is known as the Dug Hill road. South of the Cache River in the Dongola quadrangle the loess is not typical but is non-calcareous, and can hardly be distinguished from the silt loams.

SOIL TYPES

A. Upland soils.—In the upland area the variation in soils is not marked. Prevailing opinion holds that loess is present in almost all of the upland soils in degrees varying from light deposits in the eastern sections covered by this report, increasing to the west, to the true deep loess deposits on the bluffs from Dutch Creek, in the Jonesboro quadrangle, south to Thebes. The true loess contains a considerable percentage of lime, and we have found lime concretions imbedded in the banks of the streams. The loess soils, according to the "county advisers" in this region whom we have consulted, will grow good blue-grass, sweet clover, or red clover, and the presence of certain leguminous plants on top of some of these ridges shows that the soil contains considerable lime; hence is not at all acid, as many of the soils on run-down farms are apt to be.

Two soil types, the yellow silt loam and the yellow-gray silt loam, together comprise over 80 per cent of the upland soils. They differ in the fact that the yellow-gray silt loam is an intermediate phase, approaching the gray silt loam on tight clay, being a mixture of the gray silt loams with the yellow silt.

The three main soil types are shown in Plate LXXII: the mixed loam in the bottoms; the yellow silt loam on the sides of the hills and ravines; and the yellow-gray silt loam on the tops of the ridges. Roughly speaking, the last two types are of about equal area, and are so represented.

PLATE LXXIII



Topography corresponding to the soils shown in Plate LXXII. Contour interval 50 feet. Scale one inch to the mile.
Arrows indicate streams.

The soil surveyors cover each section by "forties" and their map agrees very closely with the topography (see Plate LXXIII). Near Alto Pass, when timber maps and soil maps were compared it was found that the present timber areas corresponded very closely with the yellow silt loam type of soil, the ridge tops and bottoms having been largely cleared.

The gray silt loams are also found on the ridge tops, while the yellow silt loams are below, coming to the surface on the slopes. As the topography near the bluffs on the western side is a series of narrow valleys separated by long, exceedingly narrow-topped ridges, the prevailing soil type is the yellow silt loam. At distances varying from four to five miles from the western bluff, the ridge tops become wider and the yellow-gray silt loam occurs with increasing frequency.

These two soil types are both characterized by porous, friable surface soils and pervious subsoils. They are capable of absorbing large quantities of water and are very resistant to drought. They do not bake hard when dry, but remain loose and porous.

While rated high as agricultural soils, both types are deficient in nitrogen, although the yellow silt loams of this area seem richer in nitrogen than the average upland-timber yellow silt loams.

The body of continuous timber follows closely the yellow silt loam area, not because of any relation between timber types and the physical or chemical nature of the soil, but because these soils are found over the very rough topography. Both the yellow and the yellow-gray silt loams are suitable for agriculture, but the yellow silt loam is found on the steep slopes which tend to erode if cultivated and hence have been left in timber. As a test of this statement, we have found that if the soil map of the Alto Pass region of Union county showing the yellow silt loam were superimposed over the timber map made by our party, the two would closely coincide so far as the upland area is concerned.

The soils derived from chert are apt to have a poor moisture-retaining capacity where the rock fragments are fairly large. This kind of soil resembles gravel, but the fragments are angular and flinty. The degree of chertiness is reflected in the type of tree growth, in the extremely cherty soils, the general forest of white oak, black oak, and hickory giving way on them to a very inferior post-oak type. The shortleaf pine on the western slopes of the bluffs near Wolf Lake is on a moderately cherty soil.

B. Bottomland soils.—As the eroding process is general in the uplands, the flood-plains of the secondary streams draining these uplands are constantly receiving a portion of the wash from the slopes, strips of sedimentary deposits being thus formed. With the exception of the valleys of the Big Muddy and Cache rivers, these strips are very narrow. In general such soils are mixed loams (see Plate LXXII), and since they

lend themselves readily to cropping after drainage, almost every acre of them has been cleared. An exception, however, is the gray silt loam on tight clay along the Big Muddy River. This does not drain well and may be classed as an absolute forest soil. Among the other bottomland-soil types are the yellow fine sandy loam, the brown sandy loam, brown silt loam, and drab clay loam. Cypress swamps seem to predominate on this last variety of soil.

CLIMATE

At Chester, on the upper boundary of our area, the annual rainfall is 45.18 inches and at Anna the mean temperature is 57.3 degrees F. The mildness of the climate at Anna can be judged by the fact that *Magnolia grandiflora* flourishes as a street tree. At Cairo, just beyond the lower boundary of the region, the mean annual temperature is 58 degrees F. and the annual rainfall 41.6 inches. From this it can be seen that both rainfall and temperature are favorable to tree growth; and only rarely is there a total loss of fruit due to spring frosts.

II. Milling and Logging Operations and Wood-using Industries in Southern Illinois

The sawmills of this region, portable and stationary, range in their daily cut from 2,000 to 20,000 feet. According to Seerey ('18), the smaller cut mentioned would rank a mill as belonging to Class A and the larger cut would indicate a Class B mill.

Portable mills are usually equipped with rack and pinion or cable drive and friction or belt feed or a combined belt and friction feed, though many in this region are run with a traction engine. A 25 horse-power engine, if properly handled, will keep a circular saw working to capacity and at the same time will run a small planer and edger. The owner usually has a circular saw, ranging in diameter from 54 inches upwards, with solid or inserted teeth. According to experts the diameter of the saw should be approximately one and one-half times the diameter of the largest log to be cut, that is, a 36-inch log needs a 54-inch saw and a 40-inch log a 60-inch saw. For very large logs in large mills a double circular saw must be used, that is, a smaller saw above the larger one, revolving in the opposite direction, commonly called a top-saw, so that the sawdust from the top-saw will not be thrown into the lower one, otherwise, in cutting large logs, the saw will not cut through the top of the log and the slab must be removed by means of an axe, resulting in much loss of time.

According to Seerey the life of a portable mill may be placed at 2 to 15 years, the maximum time it is operated each year being about 150 days.

The amount of lumber secured from a log depends upon several things—such as the condition of the saw and machinery, the defects in the

log, and, especially, upon the skill of the sawyer in getting the possible maximum of high-grade lumber out of every log, that is, reducing the slabs and edging to the lowest possible figure. An experienced sawyer can "size up" a log before it comes on the carriage, and will know how to turn and handle it so as to get the most desirable and best-sized pieces out of it. One method is to saw the log "alive" or through and through, edging up the boards afterwards with the circular saw. Still another plan is to slab off the boards on four sides of the log, leaving the "wane," or bark, on each board and then cutting up the squared timber into planks or boards. The "waney" boards are then sent to the edger, which removes the bark, or, some small mills may ship them, since mills are not always equipped with an edger. The slabs may be cut into fire-wood with a cut-off saw or used as fuel for the engine.

Logging operations and costs.—With this digression into mills and machinery, we may next describe a specific logging and milling operation which we took a little time to follow in detail. It was conducted at Ava, Illinois, by the Old Ben Coal Company. The timber being handled was located about $4\frac{1}{2}$ miles southwest of Ava, in Kinkaid township, Jackson county. The mill was in the S. E. corner of Section 32, T. 7 S., R. 4 W., and the cutting area included parts of sections 32, T. 7 S., R. 4 W., and Section 5, T. 8 S., R. 4 W. Land and timber had been purchased by the company and after cutting the timber the land was to be sold for farming or pasture purposes, at a price around \$15.00 an acre.

The ordinary operations connected with logging consist of felling, bucking, and loading the logs on drays or log-wagons for transportation to the mill. Skidding, which means hauling the logs for short distances to piles or skidways in the woods by means of horses or other power, was eliminated in this instance as the logs were hauled directly to the mill, about a mile distant, on log-wagons or drays.

The felling crews consisted of two men each, and for felling the trees and cutting them into log lengths they received \$3.50 per M. feet, the minimum top-diameter of logs being 12 inches, Doyle-Scribner scale. According to Seerey, two men working in timber which will run from 8 to 10 logs per 1,000 feet will ordinarily cut between 5,000 and 6,000 feet per day, the logs varying in length from 12 to 16 feet. In Illinois men could not do so well, but two men should cut 4,000 feet per day. Wages in this region have to be graded by what men can receive in the mines, so that good inducements must be offered woods workers, especially in the summer. Teamsters with their teams received about \$8.00 per M. feet for hauling logs to the mill and did their own yarding, swamping, and road-building.

The mill was above the average in efficiency and cut about 4,000 feet per day, this lumber being hauled to Ava, a distance of $4\frac{1}{2}$ miles, at a

probable cost of \$7.00 per thousand feet. The lumber was well manufactured and there was very little waste, since almost everything could be utilized either for riprap lumber for the mines, or for cap-pieces, made out of the slabs. Six men were employed around this mill and wages ran from \$3.00 to \$5.00 per day. To run such a mill there would be required a sawyer, an engineer, a setter, one slab sawyer, an off-bearer, and a man to take away sawdust. After the logs had been taken out of the trees, other crews went in to make ties and mine props out of the tops, for which they were paid by the piece. It is the custom in some places to go through and take out the young white oak trees for legs and cross-bars, as it is claimed that such trees will be badly damaged by felling the large timber. All species were being cut in this operation and the average tree would yield not far from 100 board feet. We are indebted to Mr. Charles W. Weaver, superintendent of operations, for the many courtesies extended to us—following the felling crews and making stem analyses of trees, getting information about prices, etc., etc.

Log rule.—The official rule for scaling logs in the state of Illinois is the Doyle-Scribner rule, which Chapman calls a hybrid or combination log-rule. The straight Doyle rule is based upon a rule of thumb which is supposed to make certain deductions for saw kerf and slabbing of the log, and reads: "Deduct 4 inches from the diameter of the log at the small end as an allowance for slab. Square one-quarter of the remainder and multiply by the length of the log in feet." For logs 16 feet in length this resolves itself into deducting 4 inches from the diameter at the small end and squaring the remainder, this giving the contents by the Doyle rule. For example, a 16-foot log 12 inches at the top end inside the bark would have a content of 64 board feet. This makes it very easy to apply as a rule of thumb, but for small diameters it gives very low results as compared with some other log rules—about half as much as the Vermont rule for an 8-inch log, the Doyle giving only 16 board feet where the Vermont gives 40 board feet. For large logs the Doyle rule gave large results, so for logs 28 inches and over the Scribner rule values were taken and the combined rule was known as the Doyle-Scribner. The Forest Products Laboratory, Madison, Wisconsin, in commenting upon various log rules after an exhaustive study, says: "A combined Doyle-Scribner rule, using Doyle on logs up to 28 inches in diameter and Scribner for logs 28 inches and over gives the largest possible overrun for both large and small logs." The term "overrun" means the amount by which the mill tally of lumber sawed exceeds the scaled contents of the logs on the log deck or in the woods. So far as we have investigated the subject in this region the overrun given by the Doyle-Scribner rule is from 20% to 25%, varying of course with the size and soundness of the logs and the degree of utilization practiced by the operator or in the region.

LIST OF MILLS, WITH LOCATION AND OUTPUT

Name and address of operator or manager	Location of mill or plant	Type	Condition	Daily or yearly capacity board feet
David M. Palmer, Ava, Ill.	S. E. $\frac{1}{4}$ of S. E. $\frac{1}{4}$ of Sec. 29, Tp. 6 S., R. 3 W.	Portable.	Running.	2,000 (daily)
Indian Creek Mill, Murphysboro.	N. E. $\frac{1}{4}$ of Sec. 1, Tp. 9 S., R. 3 W.	Stationary	Running.	7,000 (daily)
Old Ben Coal Co., West Frankfort.	S. E. $\frac{1}{4}$ of S. E. $\frac{1}{4}$ of Sec. 32, Tp. 7 S., R. 4 W.	Portable.	Running.	4,000 (daily)
George Chester, Ava.	N. W. $\frac{1}{4}$ of N. E. $\frac{1}{4}$ of Sec. 28, Tp. 7 S., R. 4 W.	Portable.	Running.	2,000 (daily)
Ben Phelps, Jacob.	Sec. 24, Tp. 8 S., R. 4 W.	Portable.	Running.	2,000 (daily)
Holmar Avers, Leanderville.	N. E. $\frac{1}{4}$ of Sec. 18, Tp. 7 S., R. 5 W.	Portable.	Idle.	2,000 (daily)
Matthews Lumber Co.	Sec. 16, Tp. 9 S., R. 3 W.	Stationary	Idle.	2,000 (daily)
Merchants Box & Basket Co., Grand Tower.	Sec. 25, Tp. 10 S., R. 1 W.	Stationary	Idle.	12-14 M. (daily)
Rendleman Bros., Alto Pass.	S. E. $\frac{1}{4}$ of S. E. $\frac{1}{4}$ of Sec. 19, Tp. 11 S., R. 2 W.	Stationary	Running.	100 M. (yearly)
W. A. Friese, Alto Pass.	{ S. W. $\frac{1}{4}$ of Sec. 25, Tp. 11 S., R. 3 W. { Sec. 10, Tp. 11 S., R. 2 W.	Portable.	Running.	2,000 (daily)
H. A. Dubois & Son, Cobden.		Stationary	Running.	20 M. (daily)
R. L. Lawrence, Cobden.		Stationary	Running.	150 M. (yearly)
Union Fruit Package Co., Anna.		Stationary	Running.	150 M. (yearly)
Fruit Growers' Package Co.	{ Jonesboro. { Sec. 19, Tp. 12 S., R. 2 W.	Stationary	Running.	100 M. (yearly)
Defiance Box Co., Ullin. (Defiance, Ohio)		Portable.	Running.	200 M. (yearly)
George W. Miller, Mill Creek.		Stationary.	Running.	2,000 M. (daily)
Bert Coleman, Uhedam Hollow		Portable.	Running.	2,000 M. (daily)
Hardwood Co., Ware.		Stationary	Running.	5,000 M. (daily)
Matthews Lumber Co., Vineland		Stationary	Running.	5,000 M. (daily)
Van-Sickle & Son, Thebes.	Sec. 8, Tp. 15 S., R. 3 W.	Stationary	Running.	5,000 M. (daily)
Dongola Box Co., Dongola.		Stationary	Running.	3,000 M. (daily)
Albright & Laurence, Dongola.	Sec. 25, Tp. 13 S., R. 1 W.	Portable.	Running.	2,000 M. (daily)

THE VENEER INDUSTRY

The term veneer covers thin strips or slices of wood used in the manufacture of crates, hampers, berry boxes, and baskets. The center of manufacture for this region may be said to be at Anna, Jonesboro, Cobden, Alto Pass, and Dongola. There are three kinds of veneer: sawed, sliced, and rotary cut, and most of the veneer manufactured in this region may be said to be of the last variety. The main logs going into this trade are so-called "softwoods," such as elm, sycamore, red and black gums, maple, cottonwood, and tulip-tree, which come from bottomlands that are being cleared for farming. Logs may be hauled in to the mills by dray or motor truck, shipped in on railroad cars, or rafted down the Ohio and Mississippi rivers. Very large logs are preferred for veneers, but they can be used down to 12 inches, or even less at the small end.

In making sliced or rotary cut veneers from the log, it is first cut into bolts of certain lengths depending upon the length of the lathes upon which they are turned out, some running up to 76 inches; but usually the bolts are shorter. They are then steamed for 12 to 24 hours, to soften the wood, after which they are spanned in a machine resembling a lathe and turned past the edge of a large stationary knife which may take off a continual roll like a thin piece of paper, or short pieces such as go into the sides of hampers. There may be considerable waste in this process, due to twisted grain, splits, frost cracks, seams, knots, and other defects in the logs, but with a clear sound log, the number of superficial feet of veneer secured is considerable. Rough waste may be used to fire the boilers, and the six- or eight-inch cores which are left at the center of the bolts may be used for the bottoms of berry boxes or sold to some pulp company for pulp-wood. Some of the processes in connection with the manufacture of different classes of veneered packages may now be considered in greater detail.

Bushel baskets for shipping fruit.—At present the main wood used for this purpose is black gum, as it makes a good-looking white basket. For the top hoop of the basket, oak was formerly used, but now good hoops are made from black gum and pecan, soaked before being bent. To make these hoops, which give strength to the top of the basket and over which the cover fits, logs are sent into the mill in lengths of five feet two inches. They are split into boards $\frac{7}{8}$ of an inch thick with a band-saw, having a kerf of $\frac{1}{16}$ of an inch, so that there is very little waste. These boards, after slabbing, are run through a machine with a series of small circular saws, like a lath-machine, which splits the boards into strips of a suitable thickness for bending. The main part of the basket, called the "web," is made by hand by laying strips on a circular form and joining

them at the center. These "webs" are then sent to an automatic machine which turns out about five baskets per minute. Wire handles are also put on automatically from wire in rolls and the basket is ready for the cover. Baskets are dried outside on an open porch and the loss in drying is very small.

Hampers.—In the case of hampers which are used for shipping vegetables such as sweet potatoes, the staves are of veneering, each stave 24 inches long. The bottom is made of two half-circular boards joined together with a staple, "cores" left by the circular veneer machines, being used for this purpose. Hampers are made on automatic machines, the staves being fed into the machine with the two narrow flexible strips which, after being stapled, will hold them all together. Good operators when speeding up with these automatic stapling machines, can turn out 150 hampers per hour. Another form of package turned out by the mills and in large demand for shipping peaches and tomatoes is the popular four-basket crate, the baskets nesting in a box made from strips of veneering; and some mills turn out small baskets used for shipping cantaloupes and cucumbers.

MANUFACTURERS IN THE REGION, AND PRODUCTS

Among the manufacturers whom some of the members of our survey party have visited we may mention the following:

Merchant's Box and Basket Co., Grand Tower, Illinois. Their mill is located on the Mississippi River and gets 90% of its raw material from Arkansas, Mississippi, Louisiana, Kentucky, and Tennessee. It uses from three to four million feet yearly and employs from 100 to 125 hands, using daily about 12,000 to 15,000 board feet. It manufactures berry crates, grape baskets, bushel hampers, and half-bushel hand-baskets. The woods used are mainly red gum, sycamore, tulip-tree, and tupelo, but a very little beech is used. Logs from 16 inches in diameter and upwards are preferred, and the mill can handle a bolt as long as 76 inches. According to their statement there is very little prime veneer-timber left in Illinois, the best tract, near Reynoldsville, having been cut some years ago.

Rendleman Brothers, Alto Pass. This firm has a mill in the southeast corner of Section 19, Tp. 11 S., R. 2 W., which has been running for six years. It is located near the source of supply, and is equipped with a planer and a veneer machine. It employs six hands, uses annually about 100,000 board feet, and the product is hauled to Alto Pass or Cobden.

W. A. Friese, Alto Pass. Mr. Friese has two mills, one located on Clear Creek in Section 25, T. 11 S., R. 3 W., and another in Alto Pass. The town mill uses about 20,000 board feet annually in supplying part of the local trade with baskets, while the mill out of town saws lumber and railway ties.

H. A. DuBois & Son, Cobden. This firm specializes in fruit baskets and hampers, using about 150,000 board feet annually. The foregoing description of processes of making baskets and hampers (pp. 331, 332) was obtained on a visit to their mill.

R. L. Lawrence, Cobden. This manufacturer buys most of his logs in the state, and ships his products to eight states. He uses about 150,000 feet annually and turns out barrels, fruit crates, and fruit baskets. Staves for slack barrels can be made by the veneer process, but the price of barrels has advanced so much in this region within the last few years that it almost prohibits their use, so that smaller packages, like baskets and hampers, are being used.

The Union Fruit Package Co., Anna. Mr. John C. DeWitt is the manager of this company, which is organized on a co-operative basis to furnish growers with strawberry boxes, four-basket crates, and other containers for fruits and vegetables. It uses about 100,000 board feet annually, the logs being purchased locally.

Fruit Growers' Package Company. This company has a mill at Jonesboro, and another located in the woods near Ware, not far from the toll-gate. They are among the largest manufacturers, in this region, of four-basket crates for peaches and tomatoes, melon crates, and many other kinds of packages for local and outside trade. Much of the material is cut during the winter months, and stored and allowed to season for assembling in the summer.

Two other box concerns were found in this region, the Defiance Box Company, located at Ullin, with main office at Defiance, Ohio, making crockery crates; and the Dongola Box Company, at Dongola.

NECESSITY FOR A LOCAL SUPPLY OF "SOFTWOODS" FOR VENEER PURPOSES

Since southern Illinois is a fruit and vegetable country, we believe it to be very essential to the prosperity of its business that there should be a local supply of bottomland timber, such as elm, sycamore, cottonwood, and gum, for the making of packages for shipping fruit and vegetables. This is a point which we believe companies adding to their acreage of orchards are not appreciating as they should. Some of the local mills see only a five years' supply of local logs ahead of them, which means that when supplies of this kind have to be shipped from more distant points, the grower will have to pay more for them and this increase will have to be charged up to the consumer.

Col. Greeley cites the fact that the supply of lumber for boxes is getting to be a very serious matter with the citrus growers in Florida. They use 12,000 boxes yearly, each requiring about 5½ feet of lumber, while the shippers of truck-produce require about 13,000,000 additional.

The rapid exhaustion of southern pine may in a few years greatly hamper the expansion of the citrus industry.

The fact that southern Illinois faces a similar situation should, we believe, lead men who do not need wet bottomland tracts for farming to save these woods, since their growth is rapid and there should always be a good market for the faster growing varieties in the form of logs for veneer.

CHARCOAL-MAKING PROCESSES AND YIELDS

Mr. J. E. Black, Ullin, Illinois, has a battery of six brick kilns, each with a capacity of about 60 cords, and about one mile southeast of Olive Branch, on the Illinois Central Railway, there is a battery of four kilns. Cordwood which comes from bottomlands in which the cypress has been cut out, costs about \$3.00 per cord, delivered at the plant, and the charcoal product from it is sold to companies making gunpowder. Almost any species of hardwood can be made into charcoal, but we are informed that to make the right kind of charcoal for blasting powder a mixture of the coals resulting from carbonizing different species must be made. As a rule the denser the wood the heavier the coal, charcoal made from cottonwood being about half as heavy as that from ash. For this reason, the lighter woods, such as willow and cottonwood, are better adapted to sporting powders.

The wood is cut into cordwood lengths and in the best practice is allowed to season for a year, either in the woods or at the plant. The main reason for this is that the higher water-content of the green wood necessitates more fuel for carbonization. Palmer ('14) says that hardwood is distilled in three forms of apparatus: (a) in brick kilns, (b) in retorts, and (c) in ovens. The retort is the modern form of apparatus because the valuable vapors are saved and condensed to make wood alcohol and acetate of lime, and because the wood is drawn into them on steel cars, and less work is required for charging and recharging than with brick kilns. The kiln type is only economical when the chief product desired is charcoal, for which a fair price can be obtained, and in locations where wood is fairly cheap and plentiful.

The brick kiln has a circular base, the entire structure resembling a beehive in form. After it has been filled with wood it is lit at the top and closed up except for outlet holes near the base which can be opened or closed with brick or fire clay to increase or decrease the draft. The time required for finishing a kiln depends somewhat upon weather conditions, but it is usually from 12 to 22 days, including the charging of the kiln, the cooling, and the discharging. The yield (Geer '07) per cord of wood from the brick kiln is from 45 to 52 bushels of charcoal, and prices

may vary from seven to ten cents per pound, depending upon market conditions. The fact that with oven retorts the charcoal is more or less of a by-product makes it very hard for operators of brick kilns to compete in the open market with the prices made by operators of retorts and ovens, since the latter can make a profit on other valuable products, such as wood alcohol and acetate of lime, and powder companies will not maintain kilns of their own when they can buy their charcoal in the open market for less than the cost of production.

TIES AND MINE TIMBERS RAILROAD CROSS-TIES

While tie-treating plants in the state are getting a very large majority of their ties from neighboring states to the south of us, Arkansas, Missouri, Tennessee, and Kentucky, the number of cross-ties actually produced in Illinois is by no means insignificant. Reports from ten railroad companies show that in 1921, ties to the number of 913,940 were produced in Illinois and landed along their rights-of-way. Making an allowance for two roads out of this number which did not purchase their normal number in 1921, we can safely say that one million ties is the normal output of the whole state of Illinois, and of this number from 300,000 to 500,000 would be produced in southern Illinois, the majority of these coming from the region covered by the forest survey party this past summer. Assuming that it takes 32 ties of good size to make 1,000 board feet of lumber, there would be 32,000,000 board feet of timber required for this purpose every year in Illinois.

Specifications, Grades and Sizes, Species

According to the specifications of one of the leading railway companies purchasing ties in Illinois, "All ties shall be free from any defects that will impair their strength or durability as cross-ties, such as decay, splits, shakes, or large knots, and should be made from trees which have been felled not longer than one month. All ties shall be straight, well manufactured, cut square at the ends, bottom and top parallel, and have the bark entirely removed. All ties shall be 8 feet, or 8 feet 6 inches long."

Ties according to size are graded as follows:

TABLE 8

Grade	Sawed or hewn top, bottom, and sides	Sawed or hewn top and bottom
1	None accepted	6" thick × 6" wide on top
2	6" thick × 7" wide on top	6" thick × 7" wide on top 7" thick × 6" wide on top
3	6" thick × 8" wide on top	7" thick × 7" wide on top 6" thick × 8" wide on top
4	7" thick × 8" wide on top	7" thick × 8" wide on top
5	7" thick × 9" wide on top	7" thick × 9" wide on top

On the basis of the durability of the different woods, the same railway company divides them into two classes, ties which need to be treated and those which do not, with subclasses under each of these based on relative natural durability of the wood, as follows:

CLASS U. TIES WHICH MAY BE USED UNTREATED

<i>Group Ua</i>	<i>Group Ub</i>	<i>Group Uc</i>	<i>Group Ud</i>
Black locust	"Heart" pines	"Heart" cedars	Catalpa
White oaks	"Heart" Douglas fir	"Heart" cypress	Chestnut
Black walnut		Redwood	Red mulberry

CLASS T. TIES WHICH SHOULD BE TREATED

<i>Group Ta</i>	<i>Group Tb</i>	<i>Group Tc</i>	<i>Group Td</i>
Ashes	"Sap" cedars	Beech	Elms
Hickories	"Sap" cypress	Birches	Soft maples
Honey locust	"Sap" Douglas fir	Cherry	Spruces
Red oaks	Hemlocks	Hard maples	Sycamore
	Larches	Hackberry	Butternut
	"Sap" pines		Gums

The board-foot contents of a cross-tie eight feet long (Chapman '21) may be found by looking up the log scale for a log of that length and diameter inside the bark, just as if the log were being scaled. Or the cubic-foot contents of the tie may be calculated from the basal areas of the top and bottom, converting this into board feet by the use of a converting factor. For ordinary purposes we may consider that a cubic foot is equivalent to 5.5 board feet, since in sawing a log quite a large amount is lost in edgings and sawdust. Mill men estimate that a tie eight feet long with a 6-inch by 8-inch face (a No. 3 tie) scales about 32 board feet and that 30 of such ties will make 1000 board feet of lumber. Ties which are 8½ feet long and have a 7 by 9-inch face (No. 5 tie) contain from 40 to 44 board feet each, or we may say that it takes from 23 to 25 of them to make a thousand board feet of lumber. Switch ties are cut about twice the length of ordinary ties and consequently with this greater length would have a still greater content.

Out of a total of 280,077 railroad ties purchased by one road in Illinois in 1921, we find that 155,940 came in class *Ta*, comprising such species as the ashes, hickories, honey locust, and red oaks. This shows that over half of the ties came from species that were not durable by nature, but were used because of the growing scarcity and high price of white oak and other durable species. It also shows the increasing value of many of our bottomland species which have until very recently been considered of little value for ties. The reason for this will be discussed later under the head of wood preservation.

In the summer of 1919 prices received for ties as well as the price for making them, reached their peak, the former varying near Jonesboro from \$1 to \$1.90, the higher price being received for a No. 5 tie (7 by 9-inch face) of such species as hackberry and soft maple, delivered at the

railroad. The prices paid for hewing ties varied from 30 cents for No. 1 up to 50 cents for No. 5, and about 25 cents each was paid for hauling them a distance of six miles. During the summer of 1921 prices had fallen considerably for both ties and labor, so that the best ties brought about \$1 delivered, and the cost of hewing was from 15 to 25 cents each.

Ties are produced in this region chiefly in three ways: (1) by small portable mills, sawing a large proportion of beech, (2) by farmers who get out ties during the winter or other slack periods, and (3) by professional "tie hackers" who generally work in pairs, maintaining a small temporary camp financed by the operator who has the contract. Where coal companies are clearing off timberland it is the custom to send in men after the logging to work up the tops of trees into railroad and mine ties, effecting in this way a rather close utilization of the tree contents.

Wood Preservation and Tie-treating Plants in Illinois

The increasing prevalence of preservative treatment in Illinois will vitally affect the future timber supply and forest management. Any process by which the durability of a species can be doubled or trebled will lessen to just that extent the drain upon our forests; and instead of taking a longer time to grow white oak, for example, attention may be given to cottonwood, soft maple, willow, sycamore, gum, and other fast-growing bottomland timber, on short rotations. According to C. P. Winslow, Director of the Forest Products Laboratory at Madison, Wisconsin, foresters are prone to emphasize the great loss in the forest through forest fires and say little about the amount of material saved to the country by preservative treatment. This is a phase of conservation which therefore deserves some consideration.

A complete list of the tie-treating plants in Illinois, several of which we have visited, is as follows:

American Creosoting Company,	Marion
Ayer & Lord Tie Company....	Carbondale
Joyce-Watkins Creosoting Co..	Metropolis
Indiana Tie Company.....	Joppa (Main office at Evansville, Ind.)
Kettle River Company.....	Madison
T. J. Moss Tie Company.....	Mt. Vernon and East St. Louis
C. B. & Q. Treating Plant.....	Galesburg
Midland Creosoting Co.....	Granite City

We have visited personally the plants at Marion, Carbondale, Mt. Vernon, Metropolis, and Galesburg, to get some information about processes and number of ties and amounts of other timber treated annually. In general these plants may be divided into two classes, those which preserve ties for their own railroad lines, as those of the C. B. & Q., and

those which do commercial treating for several railroads or for private companies. With the exception of the plants at Galesburg and Madison, these plants receive ties from the region now under discussion.

The railroad companies have taken the lead in timber preservation because of the increasing scarcity and high prices of railway ties, this being one class of material for which no satisfactory substitute has been invented. They have found that many species of timber not sufficiently durable for cross-ties may be made so by preservative treatment. Many of them have been creosoting timber long enough to obtain reliable data from experimental tracks laid with ties treated by various methods, upon which exact observations have been made through extended periods under all classes of climate and soil conditions.

A number of the large steam roads, for example, the Burlington in Illinois, have extensive treating plants fitted to handle large quantities of timber in an efficient manner. Starting in with cross-ties, many have found out that it effects a great saving to treat every stick of timber used for trestles, piling, bridge-stringers, and telephone poles. They have found out that all species need air-seasoning for a considerable length of time and some of them keep as much as six million feet of material in their yards for a year—which means carrying a heavy investment. The idea seems to be growing that all species are benefited by preservative treatment and that all can be treated successfully and advantageously.

Nearly all cross-ties are treated by the closed tank or "pressure process," in which the wood is subjected to treatment under pressure designed to secure a heavy absorption of the preservative. There may be as many as eight of these treating cylinders at one plant, each about 125 feet long and from five to six feet in diameter, with heavy air-tight doors which can be locked while the cylinder is being subjected to an initial vacuum or to pressure. Each cylinder will hold about 16 steel cars or "cylinder buggies," which after being loaded with 52 eight-foot ties, are drawn into the cylinders by means of cables or small donkey engines, each filling by these cars being known as a "charge." The displacement of one of these cylinders is about 3,900 cubic feet.

Preservatives used.—The principal preservatives in use at the present time are creosote oil, zinc chloride, and an emulsion of zinc chloride and creosote, treatment with the last being known as the "Card process" from its inventor. Modifications of the method known as the "pressure process" have been devised to bring about preservation without taking too much of the liquid. One of these, known as the Rueping process, is used with creosote at the plants at Metropolis and elsewhere. Since its design is to leave the creosote only in the cell walls and not in the pores of the wood cells, it is sometimes called the "empty cell" process.

Creosote has the advantage that being more or less oily, it does not wash out of the wood readily, so that it is adapted to ties in wet places. Zinc chloride, while classed as a soluble salt, has given good satisfaction and is applied with pressure in the same manner as creosote, the process being known as "Burnettizing." We were shown a red oak tie at the Mt. Vernon plant which had been treated with zinc chloride in 1899 and the wood was still sound and heavy, the main failure being where it had been cut by the tie plates. This showed a durability of 22 years, whereas red oak untreated is rated at about eight or nine years only. This would seem to belie the statement that zinc chloride is unsatisfactory because of its solubility in water. There has been complaint that it interferes with the automatic signals by its effect on the electric current.

Results of treatment and effect on different species.—Mr. J. H. Waterman, Superintendent of the Galesburg plant, rates the value of the different processes in the following order: first, straight creosote; second, the Card process; and third, Burnettizing (zinc chloride). According to his experience the average life of an untreated tie is not over four years, but over twelve years' life are got out of some of their treated ties, with the possible exception of chestnut. He believes that much depends on the thoroughness of the treatment and the time of the year when the timber is cut. Thorough air-seasoning is recommended for every stick of timber treated.

His observations upon the ordinarily less durable species are of value in this discussion. He states that cottonwood if properly treated with creosote will give as long life as any tie he handles. Beech, birch, and maple will only give about four years' service without treatment, but make good ties when properly treated. As to hard maple, his road has in Nebraska a number of these treated ties in the track and he believes that they will get twenty years of life out of 90 per cent of them because they were cut in the winter months; and the same can be said of birch, soft maple, and beech if properly handled. The latter is a species which has been brought into the market within the last few years, altogether because of the use of preservatives. Mr. Waterman further believes that durability of ties will be doubled by the use of heavy rails and tie plates, since the failure of many softwood ties is due to cutting rather than to decay.

Ordinary pressure process.—Leaving out the Rueping process, the ordinary pressure process with zinc chloride or creosote is to put the trams carrying ties or other material into the retort and draw an initial vacuum of about 25 inches for one hour, more or less according to the specifications of different railroads. The creosote is then introduced under sufficient pressure to drive the preservative into the pores of the wood, the length of time for absorption depending upon the species of wood and,

again, upon the specifications under which the contractors are working, but varying from two to three hours. The pressure is then removed, the preservative is withdrawn to the storage tanks, and the material is allowed to drip for some time before being returned on the trams into the yards. The amount of preservative is usually specified at so many pounds per cubic foot, a "full cell treatment" requiring 12 pounds per cubic foot of wood. Owing to the large amount of material kept on hand for seasoning and the space needed for storing, receiving, and dispatching it, these timber-treating plants are usually located at some distance from towns and adjacent to railway lines, with a large tract of land for buildings, spurs, and yards.

Some of these plants have been equipped for treating wood-block paving, the blocks being made at the plant from southern pines, and the process being similar to that for treating railway ties, except that the blocks are put in containers with perforated sides instead of being loaded upon trams. The plant at Granite City specializes on paving blocks and piling, and does not treat over 3,000 ties a year. It uses the Rueping process entirely.

TIMBER USED IN COAL MINES

Of the four counties coming within the scope of this report, only Jackson county mines any coal. It is credited with an output of 1,204,949 tons for the year ending July 30, 1921. The timber supply of the other three counties, however, is very important as furnishing a supply of mine timbers to adjoining counties—to Williamson, which mined 10,822,566 tons, and to Franklin, which produced during 1921 12,723,700 tons, exceeding the amount produced by any other county in the state. High freight rates, of course, have their effect upon the distance to which mine timbers are shipped, but in general we may say that the coal-mining counties have naturally preferred to save some of their own timber and buy from outside sources.

Kind and description of timber used in coal mines.—The main kinds of timber used in coal mines may be listed as follows:

1. *Cross-bars or legs.* These must be made of white or bur oak. They vary from 10 to 16 feet in length, and must be not less than seven inches at the top end, inside the bark. Thrifty young white oaks are often cut for bars when by leaving them for a few years they might grow into trees of tie size.

2. *Mine props.* Mine props may be in the round, or split from large trees, and are from 5.5 to 10 feet in length and not less than four inches at the top end. They are classed as mixed oak, which brings the best prices, and miscellaneous, which includes almost any of the bottomland species except willow and cottonwood.

3. *Mine ties.* These are of two kinds—room ties and motor ties. The former are of smaller size and are used by the miners in mining the coal out of a "room"; while motor ties must be larger, since over them the heavy motors run which convey coal to the hoisting shaft. Room ties are about 5 feet in length, of any kind of hardwood, hewed on two sides, and with a 4-inch by 6-inch face. Motor ties are usually $5\frac{1}{2}$ feet long, hewed on two sides, with a face 5 by 7 inches. Sometimes the smaller ties are sawed out by a portable mill. So far as we have seen, creosoted mine-props are not being used, since it is not intended that they shall give a service of over three or four years. For more permanent construction near shafts and in fluor-spar mines, cement or steel may be used.

4. *Mine caps. "Cap pieces."* These are pieces of boards of mixed oak, 1 inch by 6 inches by 16 inches in length, which are placed on top of mine props to tighten them up. Some of the sawmills use defective lumber for this purpose.

5. *Wooden tracking.* This is used in pieces usually 8 feet long and 3 by 4 inches in diameter, to take the place temporarily of rough or poor grade lumber which may be used to keep coal from falling down. It may be sawed at portable mills, and is worth about \$20 per thousand board feet.

6. *Riprap lumber.* This term is used to designate a kind of rough or cheap grade of lumber which may be used to keep coal from falling down in mines or is used in cars and may be sawed at portable mills. It is worth about \$20 per thousand board feet.

7. *Lagging.* Small round poles or poor-grades of slabs from portable mills used to keep coal from falling through.

8. *Sprags.* Pieces of hardwood, preferably hickory, 2 inches in diameter and 18 inches long, used by miners to thrust between the spokes of coal cars to stop them.

Besides the kinds enumerated, large amounts of yellow pine and other kinds of lumber not considered here are used for tipples, sheds, buildings, and offices.

Amount of timber required to mine a ton of coal.—This is a very hard point to determine. One operator states that ten times as much timber is required in the Danville district to mine a ton of coal as in the Taylorville district, due largely to a difference in roof conditions.

Figuring it, however, by four different methods from data given us by some of the largest coal companies on timber used and coal mined for a single period, we find by averaging the figures from five different sources, that it takes not far from .25 cubic foot of timber to mine one ton of coal, or 20,000,000 cubic feet for the whole state, not including lumber used for buildings and other construction purposes. Hall and Ingalls ('11) estimate that it takes one-fifth of a cubic foot of wood to mine one

ton of coal, agrees very well with our figure. This amount is less than that given by some other authorities. Andros ('15) says that for "long-wall mines" in District 1, from 1.5 to 3 props per ton of coal are needed and for "Rooms and Pillar" timbering from 2 to 12 props per ton of coal, depending upon roof conditions.

III. Forest Problems

FIRES

Fire is the most important single factor affecting the forests of this region, and fires must be controlled before any policy looking towards the securing of a fully stocked forest can be made effective. Some part of the continuous timbered bluff area is burned over every year. The fall of 1921 was unfavorable for forest fires because of heavy rain at the usual fire period, but with the rank vegetation now on the ground the spring of 1923 if fairly dry will be a dangerous period. Out of 33 sections in different parts of this region examined during the summer of 1921, 12 had burned over completely or partially within the last three years.

The forest-fire hazard is quite pronounced for several reasons. Where the stands are well stocked with mature trees, the forest floor is carpeted with leaves in autumn; and where the stands have been opened up too freely grass and weeds grow luxuriantly on the fertile soil. Hence, throughout the wooded area conditions favor burning. Also the continuity of the wooded areas in the bluffs permits fires to spread if once started, and it is almost certain that they will be started somewhere in the hills by hunters, by travelers, by settlers clearing land, by tie hackers or other woods workers who have no interest in the woods, by farmers burning along the edges of the woods to kill chinch-bugs, by railroad engines, by incendiaries, or by lightning. Probably hunters set more fires than any other class. Fires also burn into the hills from the Mississippi bottoms.

DIRECT EFFECTS OF FIRES

The direct damage done by fires (Hawley '21) consists in the injury to trees containing merchantable material, the injury to young growth, including reproduction, injury to the soil, and injury to the productive power of the forests. A temperature of 54 degrees Centigrade (129.2 F.) is sufficient to kill the cambium or growing layer of a tree, this layer being very much more sensitive to heat during the early part of the growing season. Trees standing upon slopes are usually damaged worst on the uphill side, if the fire is sweeping up the slope, because that side is more sheltered temporarily and there is usually a greater accumulation of leaves and litter there at the base of the tree so that the fire burns longer and more severely.

We have found trees over 12 inches breast high burned down by repeated fires, which means, of course, a direct loss of the merchantable timber in these trees. If not killed outright by the intense heat, young trees are fire-scarred, the wood is finally exposed by the peeling off of the bark, and an entrance point thus made for the spores of wood-destroying fungi which start decay at the base of the tree. In such timber a heavy discount must be allowed in making estimates. If left for seed, it is very unlikely that such trees will survive long or produce good crops.

INJURY TO REPRODUCTION

Fires kill the young growth outright, both of sprout and seedling origin, the amount of complete destruction depending on the thickness of the bark, the black oaks and hickories evidently being more fire-resistant than the white oaks. Repeated burning off of sprouts may cause an abnormal growth of young sprouts, too dense to amount to much in restocking the stand and only adding fuel to the next fire. Acorns, nuts, and other seeds are also so scorched and burned that they will not germinate no matter how favorable soil conditions may be; and the opening up of the stand through repeated fires hinders the reproduction of the better species brought into unfavorable competition with a covering growth of weeds, grass, and inferior species like sassafras, persimmon, and sumach. This fact of worthless growth, and the consequent drying out of the soil due to burning, is changing the beech-maple type of forest to the more xerophytic oak-hickory type.

INJURY TO THE SOIL

Prior to the work of Hesselman, the main value of humus in forest soils was thought to be its effect upon the physical characteristics of the soil, increasing its water-holding capacity, rendering heavy clay soils lighter and better aerated, and making sandy soils more retentive of moisture and heat. Moore ('22) shows that humus in soil or even in sand has a decided effect to stimulate the growth of tree seedlings of various pines and the sugar maple. He also says that "the nutrient value of humus and its influence on rate of growth in certain forests seems amply demonstrated. Surface-burning in a forest, by adding ashes to the soil, may stimulate growth temporarily; but since it destroys the nitrogen, which seems to be such a large factor, and allows the remaining nutrients to be rapidly carried off by rain, its ultimate result must be to seriously check growth." This may explain the low humus content of our upland timber soils in many counties as referred to by the Soil Survey. These soils have undergone repeated burning, coupled with a leaching out of their soluble humus content.

INJURY TO PRODUCTIVE POWER OF THE FOREST

Another fact emphasized by one of our field party is the injury to other trees by a reduction in the density of stocking. Through this thinning-out process due to fires, the young trees that are left lose the benefit of competition with their neighbors. In restocking a forest the most desirable trees for timber are those which have a long, straight, well-pruned trunk and a short crown. Such trees are produced only by crowding when young and by the consequent struggle upwards for the light. Under present conditions there is no crowding during the sapling and pole stages so that the young trees branch close to the ground, with not enough side shade to kill off the side branches and thus to make good, clear lumber.

This reduction of density in stands of mature timber is shown best by our stand tables (Nos. 1 and 2, pp. 313, 314) for average acres at Alto Pass and Jonesboro, where we have 43.65 trees per acre 6 inches and above in one case, and only 33.32 in the other owing to fires and culling. Normal yield-tables for hardwoods of similar age show that we should have 130 trees or more per acre in order that they may properly utilize the soil and prune each other sufficiently. Data following in tables 9 and 10 obtained (*a*) near Ava, Illinois, in a tract which, according to statements of the owner, was 35 years old and had been burned over 8 years before, and (*b*) from an unburned New England stand will bring out more strongly this diminution in the number of trees and the consequent loss of volume-growth which results.

Three quarter-acre plots were laid off in the Ava tract and the trees one inch and upwards in diameter were calipered. As can be seen in Table 9, the main species were white oak, black oak, and hickory, the percentages as follows:

White oak	51.5%
Black oak	23.6%
Hickory	15.3%
Elm	6.0%
Miscellaneous	3.6%

A comparison with an unburned inferior second-growth hardwood stand in New England (Spaeth, '20) thirty years old, is shown in Table 10 just below our figures for one acre of Ava woods. The sites, if compared on the average heights of the dominant trees, can be said to be fairly analogous, 34.4 feet in New England as against our 30 feet. A comparison of the basal areas of each acre shows that our stand was decidedly understocked, 85.3 square feet in New England as against 60.2 square feet for the Ava stand, this reduction in numbers resulting in a

much smaller yield—9.8 cords per acre for the Ava stand and 20.63 cords for New England. The mean annual growth at Ava was only 21.3 cubic feet per acre for the 35-year period as against 48.6 cubic feet in New England.

TABLE 9.—DATA ON THREE $\frac{1}{4}$ -ACRE SAMPLE PLOTS—35-YEAR STAND, UPLAND TYPE. LOCATION, SEC. 8, TP. 8 S., RANGE 4 W., AVA, ILL.
(LIGHT BURN 8 YEARS AGO)

Diameter, Inches	White oak		Black oak		Hickory		Elm		Miscel- laneous		Totals	Basal area of stands sq. ft.
	No.	Vol. cu. ft.	No.	Vol. cu. ft.	No.	Vol. cu. ft.	No.	Vol. cu. ft.	No.	Vol. cu. ft.	No. Trees	
1	3		2		24		3		1		33	.198
2	14	2.8	4	.8	19	3.8	1	.2	2	.4	40	.880
3	47	18.8	25	10.0	6	2.4	3	1.2	2	.8	83	4.117
4	47	42.3	16	11.2	4	3.2	4	3.6	3	2.7	74	6.438
5	40	56.0	15	21.0	2	2.6	4	5.6	4	5.6	65	8.840
6	11	15.0	14	35.0	0	....	5	12.5	0	....	30	5.880
7	12	40.8	9	30.6	0	....	3	10.2	1	3.4	25	6.665
8	13	57.2	2	8.8	2	8.8	0	....	1	4.4	18	6.282
9	7	39.2	3	19.5	2	12.8	....	....	....	....	12	5.304
10	4	32.0	1	8.0	....	....	....	....	....	....	5	2.725
11	0	....	0	....	....	....	....	....	....	....	0	
12	1	13.0	....	....	....	....	....	....	....	....	1	.785
Totals	199	327.1	91	144.9	59	34.6	23	34.3	14	17.3	386	48.21

TABLE 10.—COMPARISON BETWEEN AVA (ILL.) STAND
AND ONE IN NEW ENGLAND*

	Total number of trees	Total basal area of stand sq. ft.	Average height in feet	Total volume in cu. ft.	Average D.B.H. inches	Age yrs.	Volume in cords	Mean annual growth cu. ft.
Ava (Ill.)								
$\frac{3}{4}$ -acre basis	386	48.2	30	558.2	5.0"	35	7.30	15.9
One-acre basis	441	60.2	30	747.7	5.0	35	9.8	21.3
New England								
1-acre basis, second- growth hardwoods.	1,515	85.3	34.4	1,460	3.21	30	20.63	48.6

EFFECT OF SEVERE BURNING UPON YOUNG STANDS

The effects of fire upon one stand are shown by the following figures, which were carefully taken on a quarter-acre plot in a thirty-year old stand where a severe fire had occurred in 1917. The trees were tallied, according to diameter, under two headings, "alive" and "dead," the diameter ranging from one inch to eight inches. We saw trees of this

*See Table 9 and pages 344-345.

latter size which had been injured beyond any hope of recovery. As can be seen from the final figures, 70% of the stand had been killed, reducing the living trees from 632 to 188 per acre. A quarter-acre stand examined under similar conditions, but unburned, showed that there were on it 200 trees six inches and over in diameter, or 800 thrifty trees per acre.

TABLE 11.—SHOWING FIRE DAMAGE ON $\frac{1}{4}$ -ACRE SAMPLE PLOT, BURNED IN 1917, SECTION 8, TP. 8 S., RANGE 4 W., NEAR AVA.

<i>Species</i>	<i>Alive</i>	<i>Dead</i>
White oak.....	16	26
Black oak.....	8	28
Dogwood.....	7	10
Persimmon.....	1	0
Hickory.....	3	6
Sassafras.....	6	18
Black gum.....	2	14
Mulberry.....	..	1
Tulip-tree.....	..	2
Elm.....	1	1
Cherry.....	3	1
Ash.....	..	4
Totals.....	47	111

Per cent killed, 70%

Note.—The total number of seedlings and saplings ranging in diameter from 1 inch to 8 inches, was 158, or 632 per acre. The slope, exposed only in spots, was 30 degrees towards the north, ground grassy, with bare soil. Fire had resulted in a succession of sassafras, sumach, and grape-vines, with which the better species of seedlings would have to compete for light and growing space.

EROSION

Weller et al ('20), in speaking of topography and farming in Hardin county, say that not over half the total acreage is under cultivation and that gullyng has followed the abandonment of the land. Steep slopes made cultivation difficult and also favored the washing away of the soil whose upper layers at least had been enriched by the organic matter deposited by the growth of plants and trees. They believe that for the future good of the county, "it would be well if all cleared lands having slopes of more than 600 feet per mile were reforested."

It seems that, in Union county at least, a separation of lands into those which will gully and those which will not on the basis of slope alone will hardly hold, since we have found erosion to be very serious on some long, gentle slopes of not over $5\frac{1}{2}$ degrees, while other slopes of 23 degrees have withstood clearing and pasturing without showing serious signs of erosion. There are other factors which must be considered, such as the character of the soil and subsoil, the maintaining of the humus content of the soil by better methods of cropping, and the vigilance of the owner in filling up gullies as soon as they start. The disposition of gullied lands really brings up the question of an economic survey of such doubtful

lands—a project which is a part of the program of the Natural History Survey.

Speaking of the encroachment of the forest upon the prairie through erosion along the water-courses, and of the fact that the organic matter in forest soils is only about 25 to 50 per cent of the amount present in adjoining prairie soils, Sampson ('21) says: "The farmers of the state have been slow in recognizing this effect of floral history upon the present value of soils. In my own community in the Southern Illinoisan glaciation the clearing and cultivation of forested areas seemed to have an alluring appeal entirely unrelated to economic values. Many of the farmers continued to clear the forest in spite of the fact that some of the forested areas after ten to fifteen years of cultivation yielded no better crops than adjacent prairie areas that had been cultivated for forty years. Many of the slopes formerly protected by forest vegetation have been cleared, farmed for a few years, and then abandoned to the forces of erosion. An intelligent constructive forest policy, that can be taught and convincingly explained to the farmers, is the only hope for remedying these regrettable conditions."

GRAZING

It is not the custom to graze the western section of the highlands where the wooded areas are extensive and relatively continuous. Here the clearings are fenced, while the wooded areas are not—probably because it involves too much trouble and expense. Unless opened up by heavy cuttings or repeated burning, the forest normally shades out the grasses so that very little pasturage is afforded. A heavy growth of grass or weeds indicates to the forester that the stand is not fully stocked, and our stand tables of the average acre for the Alto Pass and Jonesboro quadrangles, as cited previously, show this condition graphically. There is enough lime in the soil to favor the growth of blue grass, Japanese clover, blue stem, and sedge, and all of these varieties were found in the woods. It is unlikely that this rough wooded section will ever be made a field for cattle-raising on a large scale since the woods do not yield sufficient forage in dry seasons, and if cleared the extremely steep slopes will erode and form gullies.

Elsewhere in the highlands the woods generally occupy the slopes or ravines. Here the forests are more of the wood-lot type or else are strips along the slope. These wooded areas are often grazed to supplement the other pastures. Here grazing may cause serious ultimate loss, since the reproduction will be destroyed and grasses encouraged. The land has been kept in timber because it is too steep to clear, yet continued pasturing results in the disappearance of the timber and with it the top soils.

IV. Forest Policy and Management

The forestry problem in this region may be discussed with reference to three kinds of forest: (1) the large, more or less continuous tract of upland timber extending from Thebes to Chester which we have called the western region, which is most important for a future supply of cross-ties, mine props, and lumber; (2) farm wood-lots which are scattered and usually surrounded by roads; and (3) the overflow bottomlands, some already included in organized drainage projects, which will not be farmed for some years—at least not during the short rotation required to grow a timber crop of the faster-growing bottomland species.

THE UPLAND TIMBER BELT

The upland timber belt presents some interesting problems. Dunlap ('21) mentions a fact in Missouri which finds its counterpart in this region, since this is a continuation of the Missouri Ozarks. He says that in this Missouri area there are from 5 to 10 millions of acres of timberland which are producing only three or four ties per acre per year when they might be producing ten ties per year. The technical side of timber-growing in such a region is, according to him, quite easy, being largely a matter of suppressing forest fires and prohibiting grazing—at least while the areas are reproducing. A combination of forestry in the hills and farming in the narrow valleys will furnish employment for farmers in summer and for woods workers in winter, thus bringing about a better economic and social condition; whereas destruction of the timber means abandonment of many farms and decreased revenue to their owners.

Where private owners and companies do not take sufficient interest in these large tracts to protect them, the question is one of the wisdom of enforcing certain silvicultural requirements in the interest of the public—which undoubtedly is concerned in a permanent timber supply—or of state or other public ownership of such tracts. Whenever the time is ripe for the state to purchase these lands—after a careful valuation—to protect them from fire, to carry on improvement cuttings and thinnings—thus affording at times a revenue to reduce the initial investment—and to hold them for a future timber supply and protection forest, this would be one possible solution. By means of its aggregation as a unit capable of successful forest-management, and its nearness to markets whose demands promise to increase rather than to diminish, the entire situation of this tract is both unique and strategic in Illinois, and we know of no other equal area in the state which combines like advantages.

OUTLINE OF PROPOSED FIRE-PROTECTION SYSTEM FOR UPLAND TIMBER BELT

In general, the attitude of these timber owners is favorable to protection, and their co-operation could be secured if they were convinced

that effective protection could be given. The essential parts of such a system are fire prevention and fire control.

The necessary steps in the direction of fire prevention would be a campaign of education emphasizing the need of fire protection, and the posting of notices explaining the fire danger and the penalties for starting fires. Actual fire control will require (1) a centrally located station where a lookout may be established. At times during the fire season a lookout man might not be able to locate fires because the smoke in the hills makes seeing over five miles very difficult, and his main work would be telephoning over the district to find out about the presence of fires. (2) A division of the area into districts, with telephone connections from the lookout station, and a responsible person in each district closely in touch with woodland owners who will assist in assembling and organizing men for fire-fighting.

This system should work out about as follows: If any one notices a fire he telephones its location and probable size to the lookout man, who, in turn, calls up the district leader and gives him the details so far as he has learned them. The district leader summons local help and puts out the fire, which would usually not be difficult if fires are caught when they start, and the men properly equipped with tools. The lookout man would receive a monthly wage during the fire seasons of spring and fall, giving his entire time to the work. The district leader and the local fire fighters would be paid for the number of hours actually spent in fire-fighting. Such fires can be whipped out with brooms, burlap bags dipped in water, or green brush, and the most important point is to get to the fire early with from ten to twelve men. The keeping of important ridge trails and roads scraped bare might also be helpful wherever such roads and trails would serve as a means of stopping fires or as a vantage point for fighting them as they came up to the top of the ridge. So far as we have seen, these roads are well located for fire lines, and it would be neither a difficult nor an expensive matter to keep them open.

THE SO-CALLED FARM WOOD-LOTS

The scattered farm wood-lots are being fairly well managed on the whole, many of them being held by the older citizens who see the advantage of conserving them and who are deriving some profit from the sale of timber at more or less regular intervals. Timber alone on forty acres of such land sells for \$1,000, or \$25 per acre, with no expense to the owner of handling it, aside from fire protection. Those farmers who do not appreciate the advantage to themselves or to others of taking care of their timber can be reached through the county farm advisers.

THE OVERFLOW BOTTOMLANDS

Since a very large proportion of the bottomlands of the Mississippi, Big Muddy, and Cache rivers yet in timber will in time be cleared and cultivated, the main work here consists of separating those areas which can not be drained from those which are true farming soils. Some of these stands, after they have been cut over by veneer or lumber companies, still contain a good stock of bottomland species which grow very rapidly and will soon be again of merchantable size. We have been told by a large manufacturer of veneer material in the Cache River district that he has enough of this kind of land with gum up to ten inches in diameter on the stump to supply a charcoal company with wood for ten years. Willow and cottonwood will likely dominate such stands after a partial clearing of the other hardwoods, and willow can be used for charcoal wood or excelsior, and cottonwood is now being marketed for soda pulp on the upper parts of the Mississippi and Illinois river bottoms. The erection of up-to-date wood-distillation plants and a pulp mill to use such bottomland hardwoods might apparently be a good business investment and distinctly favor forestry in this region. Besides, there is a demand for about 2,000,000 board feet of "softwoods" of the larger diameters coming from the veneer mills located in an important fruit-growing section of the state; and we have been informed by operators of such mills that when the local supply of this bottomland timber is exhausted, which will probably be within five years, they will be compelled to move to Arkansas or Missouri, nearer the source of supply.

V. Volume and Growth Studies

The volume and growth of any species are best studied by making complete stem analyses of felled trees, since haphazard stump measurements are of little value, especially if made from a small number of trees. It was difficult to find in southern Illinois lumbering operations suited to the requirements for growth measurements, but two very good opportunities were afforded, one at Ava, and another at Indian Creek, near Murphysboro. One disadvantage in following the choppers is that logs are not cut by them in the ten-foot lengths preferred by the forester and the cutting is not carried up to a certain minimum top diameter, as the smallest diameter of the logs depends on the degree of utilization characteristic of the region. During the summer, however, complete stem analyses were made of 67 black oaks, 68 white oaks, and 33 trees classed as miscellaneous, along with many measurements for the volume tables. In the Appendix, pp. 367-371, are given the results obtained from these stem analyses of white and black oak, but a study of the growth of

tulip-tree, hickory, sycamore, and other species must be deferred until more measurements are secured in this region. It is realized that the number of black and white oak trees is small, but it is believed that the figures are reliable for the area covered by our map.

STEM ANALYSIS

For the benefit of those who are not familiar with the field measurements taken on an individual felled tree, a stem analysis blank such as was used is reproduced on page 352, filled out as it was in the field by a party of three men. Two men make the required measurements for each section of the tree as sawn by the choppers, and a third makes the record. The diameter at $4\frac{1}{2}$ feet above the ground (D. B. H.) can be taken with calipers before felling, or measured with a $4\frac{1}{2}$ foot stick held on the bole of the tree after felling.

It will be seen that this sheet contains all of the data necessary to a calculation of the growth of the tree in height, diameter, and volume, so the rest of the work can be done in the office. We have also the growth at different ages as shown at different heights above the ground. Since we know the diameter inside the bark and the length of each section, we have all the data needed to scale the logs by any log rule or to compute in cubic feet the volume of the separate logs, stump, or top. It will be noticed that the fifth section of this tree, left in the woods on account of crook, had a length of 12 feet and diameters at the ends inside the bark of 16.3 and 12.9 inches respectively, and that it scaled 61 board feet, and measured 9.84 cubic feet by the Smalian formula for computing volumes. By adding together the contents of all the unused pieces for the whole number of trees analyzed, a very reliable discount or "cull factor" for crook or rot can be obtained for any species, and this can be applied to the total estimate for that species.

The procedure in the office is as follows, and Graphs I (p. 372), III, IV, V, and VI illustrate some of the steps taken.

1. Separate the blanks into classes based on their D. B. H. (diameter breast-high); for example, putting 10.6-inch trees into the 11-inch class, 10.5-inch trees into the 10-inch class.

2. Make curves of height and D. I. B. (diameter inside bark) for each D. B. H. class represented, plotting D. I. B. at the top of each section as recorded, including the stump.

3. From the curves thus plotted, read off sets of D. I. B. tables for logs at 8, 10, 12, 14, etc., feet above an average stump height of 2 feet.

4. Harmonize the last readings by making curves for each 2- or 4-foot section, based on diameters breast-high. Read off for final taper-table (see Table XII, App.), giving the D. I. B. at different heights above the

STEM ANALYSIS FIELD-SHEET

Locality, Ava, Illinois

Species, Tulip-tree

Date, Oct. 8, 1921

No. 69—Stump height, 3 feet

[illegible]

Tree class, Dominant.

Length of crown, 37 feet.

Width of crown, 35 feet.

stump for different diameters breast-high. It can be seen that with such a table, which is a "taper table," the size of the average tree can easily be ascertained, and that all the data are in hand necessary for scaling its contents by any log rule or for computing its volume in cubic feet.

5. Plot curves of total and merchantable heights based on D. B. H. for both black and white oaks. Also make up tables from curves showing the board foot and cubic foot contents of trees based on D. B. H.

6. To get volumes based on age, plot the measurements taken under the heading "Distance on average radius from center to ring by decades" shown on the field sheet. Taking the stump section first, plot the diameter grown in ten years, by doubling the radius measurement each time. Diameter inside the bark is used as the ordinate and age as the abscissa for the curve.

7. Repeat the same procedure for the other sections, or logs, marked 1, 2, 3, 4, 5, and 6, on separate sheets of cross-section paper, and finally assemble all of these curves on one sheet. In this case the curves for different lengths are moved out to the age corresponding to the number of years required to grow up to that height from the ground.

8. With such a set of curves of diameter-growth at different heights, read off the time required to grow a log of any length or any top diameter inside the bark by following with the eye a line from the D. I. B. across to the curve representing the length desired. Project a line down from that curve to the base line and read the age required for the growth from the ground of such length of log.

9. After this set of curves is made, the results can be read off to form a table, and the volume of the logs can be computed, since their top diameters and lengths are known.

As stated by Pegg ('19), working up the data from stem analysis sheets can be greatly facilitated by the use of an adding machine and a slide rule.

BIBLIOGRAPHY

Andros, S. O.

1915. Coal mining in Illinois. Bul. 13, Ill. Coal Mining Investigations.

Baker, Willis, M.

1921. One cord an acre a year. Jour. Forestry, 19 (No. 7) : 755-756.

Chapman, H. H.

1921. Forest mensuration. Wiley & Sons, New York.

Colyer, Frank H.

1922. The geography of the Ozarks. Trans. Ill. Acad. Sci. 14: 36-43.

Deam, Charles C.

1915. Fifteenth Annual Report Indiana State Board of Forestry. Conservation Commission of Indiana.

1921. Trees of Indiana. Department of Conservation, State of Indiana, Publication 13. Indianapolis.

Dunlap, Frederick N.

1921. Growth of oak in the Ozarks. Research Bul. 41, Missouri Agr. Exp. Sta. Columbia, Mo.

Fuller, George D., and Miller, R. B.

1922. Forest conditions in Alexander county, Illinois. Trans. Ill. Acad. Sci. 14: 92-108.

Geer, W. C.

1907. Wood distillation. Forest Service Circular 114, U. S. Dept. Agr., Washington, D. C.

Graves, Henry S.

1921. New Hampshire and the new movement in forestry. Published by the Society for the Protection of New Hampshire Forests, 4 Joy Street, Boston.

Hall, R. C., and Ingall, O. D.

1911. Forest conditions in Illinois. Bul. Ill. State Lab. Nat. Hist., Vol. IX, Art. IV.

Hawley, L. F., and Palmer, R. C.

1914. Yields from the destructive distillation of certain hardwoods. Bul. U. S. Dept. Agr. No. 129.

Hawley, Ralph, C.

1921. The practice of silviculture, with particular reference to its application in the United States. Wiley & Sons, New York.

Lovejoy, P. S.

1919. The segregation of farm from forest land. Jour. Forestry, 17 (No. 6): 645, 646.

Moore, Barrington

1922. Influence of certain soil factors on the growth of tree seedlings and wheat. Ecology, 3 (No. 1): 69-70.

Palmer, R. C.

1914. Distillation of hardwood. Compiled from bulletins of the U. S. Forest Service. Forest Products Laboratory, Madison, Wisconsin.

Pegg, Ernest C.

1919. Mechanical aids in stem analysis. Jour. Forestry, 17 (No. 6): 682-685.

Recknagel, A. B.

1916. A practical application of Pressler's formula. Forestry Quarterly, 14 (No. 2): 263.

Ridgway, Robert

1883. Notes on the native trees of the lower Wabash and White River valleys in Illinois and Indiana. Proc. U. S. Nat'l Mus. 5: 49-88.

1895. Additional notes on the native trees of the lower Wabash Valley. Proc. U. S. Nat'l Mus. 17: 409-421.

Sampson, Homer C.

1921. An ecological survey of the prairie vegetation of Illinois. Bul. Ill. State Nat. Hist. Surv. 13 (Art. 16): 547-548.

Savage, T. E.

1908. The Lower Palaeozoic formations in southwestern Illinois. Am. Jour. Sci. 25: 431-443.

1909. The Lower Palaeozoic formations in southwestern Illinois. Ibid. 28: 509-519.

1910. The Pre-Devonian of southern Illinois. Yearbook Ill. Geol. Surv., 1909, Bul. 16: 304-341.

1920. The Devonian formations of Illinois. Am. Jour. Sci. 49: 169-182.

Savage, T. E., and Shaw, E. W.

1912. Geological atlas of the United States, Murphysboro-Herrin folio. Surveyed in co-operation with the Geological Survey of Illinois.

Seerey, Daniel F.

1918. Small sawmills, their equipment, construction and operation.
Bul. 718, U. S. Dept. Agr. Contribution from the Forest Service,
Washington, D. C.

Spaeth, J. Nelson

1920. Growth study and normal yield tables for second growth hard-
wood stands in New England. Harvard Forest Bul. No. 2. Peter-
sham, Mass.

Trelease, Wm. T.

1896. Juglandaceae of the United States. Seventh Ann. Rep. Mo.
Botanical Garden, p. 25.

Weller, Stuart, et al., in co-operation with the U. S. Geol. Survey

1920. The geology of Hardin county and the adjoining part of Pope
county. Bul. 41, Ill. State Geol. Survey, pp. 43-44. Urbana,
Illinois.

APPENDIX

VOLUME TABLES FOR LEADING SPECIES, AND TAPER AND GROWTH TABLES AND GRAPHS FOR BLACK AND WHITE OAK

From measurements taken on felled trees of leading species it was possible to make local volume tables for white and black oak. Since the number of field measurements made on trees of other species was not sufficient for the formation of a satisfactory basis for volume tables, it was thought wise to collect in the appendix the best tables extant for the other species which the wood-lot owner would ordinarily encounter. For convenience in citing to this article these tables are numbered consecutively beginning with one (I), but the original, author's, table-number, if any, is retained as facilitating reference to the table in its original connection.

TABLE I*

TABLE VII.—SHOWING TOTAL HEIGHT, CLEAR LENGTH AND VOLUME
FOR CYPRESS OF DIFFERENT DIAMETERS. MISSISSIPPI BOTTOMS

Diameter Breast High Inches	Total Height Feet	Clear Length Feet	Volume [Doyle Rule] Board Feet
10	78	43	89
11	82	46	116
12	85	49	147
13	88	53	184
14	90	56	231
15	93	59	280
16	95	62	336
17	97	65	399
18	100	68	468
19	102	71	546
20	104	73	632
21	106	76	715
22	108	79	817
23	109	81	928
24	111	83	1,037
25	113	85	1,153
26	114	87	1,277
27	116	89	1,309
28	117	91	1,551
29	119	92	1,700
30	120	93	1,840
31	122	94	1,986
32	123	95	2,139
33	124	96	2,290
34	125	97	2,450
35	126	97	2,620
36	128	98	2,800

*From the Woodsman's Handbook, Part 1, by Henry S. Graves, U. S. Department of Agriculture, Bureau of Forestry, Bulletin No. 36, 1903.

TABLE II*
TULIP TREE (YELLOW POPLAR)

Age Years	D. B. H. Outside Bark Inches	Height Feet	Volume [Doyle Rule] Board Feet
60	10	78	22
68	11	82	32
75	12	86	47
82	13	89	63
90	14	92	87
97	15	95	113
104	16	97	150
112	17	99	190
120	18	101	238
128	19	103	290
136	20	104	352
144	21	105	420
152	22	106	490
160	23	107	565
169	24	107	644
178	25	108	725
186	26	108	813
195	27	109	905
204	28	109	1,002
212	29	110	1,106
221	30	110	1,215
230	31	111	1,327
240	32	111	1,445
248	33	112	1,563
258	34	112	1,685
267	35	113	1,811
276	36	113	1,940
286	37	113	2,074
296	38	114	2,210
306	39	114	2,342
317	40	115	2,475

*From measurements taken on 403 trees in Scott and Anderson counties, Tennessee, by F. E. Olmsted, of the U. S. Forest Service.

TABLE III*

"Table 8 gives cubic contents of hickory trees according to diameter and merchantable length. It is based upon the measurements of 630 trees. By its use the total contents of a tree may be estimated without reference to the individual logs."

TABLE 8—Cubic contents of hickory according to diameter and merchantable length.

Diameter breast- high— inches	Merchantable length—feet														Diam- eter inside bark of top— inches
	5	10	15	20	25	30	35	40	45	50	55	60	65		
	Volume—cubic feet														
5.....	1.0	1.8	2.3	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	4	
6.....	1.3	2.5	3.2	3.6	.....	.....	.....	.....	.....	.....	.....	.....	.....	5	
7.....	1.6	3.2	4.2	5.0	5.7	.....	.....	.....	.....	.....	.....	.....	.....	6	
8.....	2.0	4.0	5.4	6.5	7.5	.....	.....	.....	.....	.....	.....	.....	.....	6	
9.....	2.5	4.8	6.6	8.2	9.6	10.0	.....	.....	.....	.....	.....	.....	.....	7	
10.....	3.0	5.8	8.1	10.0	11.5	13.0	.....	.....	.....	.....	.....	.....	.....	8	
11.....	3.5	6.9	9.7	12.0	14.0	16.0	18.0	.....	.....	.....	.....	.....	.....	8	
12.....	4.1	8.0	11.5	14.5	17.0	20.0	21.5	23.5	.....	.....	.....	.....	.....	9	
13.....	4.8	9.3	13.5	17.0	20.5	23.5	26.0	28.5	31	.....	.....	.....	.....	10	
14.....	5.5	10.5	15.5	20.0	24.0	27.5	31.0	34.0	37	.....	.....	.....	.....	11	
15.....	6.2	12.0	17.5	23.0	27.5	32.0	36.0	39.0	43	.....	.....	.....	.....	11	
16.....	7.0	14.0	20.0	26.5	31.0	36.0	41.0	45.0	50	54	.....	.....	.....	12	
17.....	8.0	15.5	23.0	29.5	36.0	41.0	46.0	51.0	56	61	66	.....	.....	13	
18.....	.....	17.5	25.5	33.0	40.0	46.0	52.0	58.0	63	69	74	.....	.....	14	
19.....	.....	19.5	28.5	37.0	45.0	52.0	58.0	64.0	70	76	82	.....	.....	14	
20.....	.....	21.5	32.0	41.0	50.0	57.0	64.0	71.0	78	84	90	97	103	15	
21.....	.....	24.0	35.0	45.0	54.0	63.0	71.0	79.0	86	93	100	107	113	16	
22.....	.....	26.0	38.0	50.0	60.0	69.0	77.0	86.0	94	102	110	118	126	16	
23.....	.....	28.5	42.0	54.0	65.0	75.0	84.0	93.0	102	111	120	128	137	17	
24.....	.....	31.0	45.0	59.0	70.0	81.0	91.0	102.0	111	121	130	139	148	18	
25.....	.....	34.0	49.0	64.0	76.0	88.0	99.0	110.0	121	130	140	149	158	19	
26.....	.....	36.5	53.0	69.0	82.0	95.0	107.0	119.0	130	140	151	161	171	19	
27.....	.....	.....	57.0	74.0	89.0	103.0	116.0	128.0	140	151	162	173	183	20	
28.....	.....	.....	61.0	80.0	97.0	112.0	125.0	137.0	149	161	173	185	197	20	

*From Bulletin 80, Forest Service, U. S. Department of Agriculture, "The Commercial Hickories," by Anton T. Boisen and J. A. Newlin, 1910.

TABLE IV*
TABLE NO. 16—VOLUME TABLE FOR RED MAPLE

Diameter, breast high (inches)	Total height of tree (feet)							Basis (trees)
	20	30	40	50	60	70	80	
	Cu. Ft.	Cu. Ft.	Cu. Ft.	Cu. Ft.	Cu. Ft.	Cu. Ft.	Cu. Ft.	
2, . .	0.25	0.35	0.55	—	—	—	—	59
3, . .	.60	.71	1.00	1.2	—	—	—	51
4, . .	1.00	1.30	1.65	2.0	—	—	—	36
5, . .	—	2.15	2.40	3.0	3.6	—	—	38
6, . .	—	—	3.45	4.3	5.2	6.2	—	42
7, . .	—	—	4.70	5.9	7.1	8.4	—	25
8, . .	—	—	6.05	7.8	9.4	10.8	11.8	39
9, . .	—	—	7.65	10.1	12.0	13.5	14.8	28
10, . .	—	—	—	12.7	15.0	16.7	18.2	20
11, . .	—	—	—	15.6	18.5	20.5	22.0	23
12, . .	—	—	—	18.9	22.5	24.8	26.4	10
13, . .	—	—	—	22.6	26.8	29.7	31.4	9
14, . .	—	—	—	26.8	31.6	35.0	36.7	8
15, . .	—	—	—	31.5	37.0	40.7	42.7	3
16, . .	—	—	—	36.6	43.2	47.0	49.7	4
17, . .	—	—	—	—	—	—	58.4	2
								397

*This volume table was constructed by E. E. Carter and first published in the Bulletin of the Harvard Forestry Club, Vol. 2, 1913. A revised and enlarged form of it appeared in "The Northern Hardwood Forest: Its Composition, Growth and Management," Bul. 285 of the U. S. Dept. of Agr., pp. 61-63.

TABLE V
COMPOSITE VOLUME-TABLE FOR WHITE OAK
CONTENTS IN BOARD FEET

D. B. H. inches	Ava table (Maine rule)	Maryland table (Maine rule)	By Doyle- Scribner rule	By Doyle-Scrib- ner rule, plus 25% over-run
8	9	4	2	2
9	18	15	4	5
10	28	20	10	12
11	41	25	16	20
12	51	50	24	30
13	77	65	34	42
14	97	80	48	60
15	120	100	65	81
16	147	150	84	105
17	172	175	105	131
18	222	210	143	169
19	245	235	168	210
20	285	260	207	259
21	323	295	243	304
22	366	325	281	350
23	413	465	329	411
24	464	510	372	465
25	520	560	426	532
26	582	600	467	584

N. B.—The figures in column 4 of the table give what an average tree of a certain diameter should actually saw out at the mill. The difference between what it saws out and its scale in the woods or on the log-deck is called "over-run." The figures in column 2 were derived from contents of trees measured at Ava, Jackson county, scaled by the Maine rule. The figures in column 3 of the table were secured from State Forester F. W. Besley, for white oak trees in Maryland which were scaled by the Maine rule.

TABLE VI*
COMPOSITE VOLUME-TABLE FOR BLACK OAK
CONTENTS IN BOARD FEET

D. B. H., inches	Ava table (Maine rule)	Maryland table (Maine rule)	By Doyle- Scribner rule	By Doyle-Scribner rule, plus 25% over-run
8	20	12	4	5
9	39	15	15	19
10	51	20	20	25
11	64	30	28	35
12	83	45	37	46
13	103	55	51	64
14	129	70	70	88
15	154	105	89	101
16	185	120	111	136
17	215	140	148	185
18	263	165	184	230
19	289	240	217	271
20	344	275	259	324
21	394	315	304	380
22	455	355	376	470
23	506	400	409	511
24	560	445	464	580
25	621	490	515	639
26	695	550	605	756
27	770	605	651	814
28	845	665	720	900
29	920	725	798	998
30	1,000	805	900	1,125

*The explanations below preceding table for white oak, are also applicable to this table.

TABLE VII*
VOLUME TABLE FOR RED OAK
(BASED ON 130 TREES MEASURED AT NEW HAVEN, CONN.)

Diameter breast high, inches	Height of tree in feet							
	20	25	30	35	40	45	50	55
	Merchantable cord-wood in cubic feet [†]							
5	1.23	1.61	1.91	2.24	2.55	2.91	3.12	3.40
6	1.78	2.31	2.83	3.31	3.77	4.22	4.61	5.04
7	.....	.....	3.79	4.40	5.08	5.68	6.25	6.79
8	.....	.....	4.88	5.75	6.56	7.31	7.99	8.75
9	.....	.....	.....	.....	8.31	9.27	10.13	10.97
10	.....	.....	.....	.....	.....	.....	12.62	13.64
11	.....	.....	.....	.....	.....	.....	15.70	16.87

TABLE VII* (continued)

Diameter breast high, inches	Height of tree in feet						
	60	65	70	75	80	85	90
	Merchantable cord-wood in cubic feet						
5	3.66	.....	.....	.....	.....	.....	.....
6	5.45	5.81	6.16	.....	.....	.....	.....
7	7.32	7.81	8.31	8.78	9.27	.....	.....
8	9.43	10.07	10.70	11.31	11.93	.....	.....
9	11.76	12.62	13.31	14.04	14.75	.....	.....
10	14.63	15.62	16.52	17.42	18.30	19.20	.....
11	18.04	19.16	20.18	21.17	22.15	23.12	24.06
12	22.33	23.62	24.90	26.04	27.15	28.16	29.14
13	27.33	28.85	30.34	31.62	32.98	34.21	35.40

*From "Forest Mensuration," by Henry S. Graves.

†Cubic feet can be converted into cords by dividing by 90.

TABLE VIII*
TABLE 7.—BLACK WILLOW—MISSISSIPPI VALLEY [DOYLE RULE]

Diam- eter breast- high	Total height of tree—feet								Diam- eter inside bark of top	Basis
	60	70	80	90	100	110	120	130		
	Volume—board feet									
Inches									Inches	Trees
14	52	64	82	100	130	140	.....	.....	10	.....
15	60	80	100	120	150	160	.....	.....	11	2
16	68	97	120	150	170	180	190	.....	12	3
17	73	110	150	170	190	210	220	.....	12	11
18	79	130	170	200	220	240	250	270	13	9
19	.....	150	200	230	250	270	290	310	14	6
20	.....	180	230	270	290	310	330	350	14	12
21	.....	200	260	300	330	360	370	390	15	23
22	.....	230	290	340	370	400	420	440	16	25
23	.....	260	330	380	410	450	470	490	17	23
24	.....	290	360	420	460	500	520	540	17	23
25	.....	.....	400	470	510	550	570	600	18	15
26	.....	.....	450	510	560	600	620	660	19	15
27	.....	.....	490	560	610	650	680	710	19	16
28	.....	.....	540	610	660	710	740	770	20	9
29	.....	.....	590	660	720	760	800	840	21	7
30	.....	.....	650	710	770	820	860	900	22	8
31	.....	.....	.....	760	820	880	920	970	22	8
32	.....	.....	.....	810	870	940	990	1,040	23	3
33	.....	.....	.....	860	920	1,000	1,050	1,100	24	6
34	.....	.....	.....	920	980	1,060	1,120	1,170	24	3
35	.....	.....	.....	970	1,030	1,120	1,190	1,240	25	1
36	.....	.....	.....	1,020	1,090	1,180	1,250	1,310	26	1
										229

*From Bul. No. 316, U. S. Dept. Agr.: "Willows: their Growth, Use and Importance," by George N. Lamb.

TABLE IX
VOLUME TABLE—BEECH

Frothingham, 1915

U. S. Forest Service Bulletin No. 285

Michigan: Based on 285 trees

D.B.H.ob in inches	Merchantable Volume in Board Feet						
	Number of 16-foot logs						
	1	1½	2	2½	3	3½	4
10	22	32	47	67	87	110	
11	25	36	52	77	100	130	
12	29	42	61	91	120	150	170
13	35	50	74	110	140	170	200
14	42	60	92	130	170	200	230
15	50	75	120	160	200	230	270
16	.....	.....	150	190	230	270	310
17	.....	.....	180	220	270	310	360
18	.....	.....	220	260	310	350	410
19	.....	.....	.....	290	350	400	460
20	.....	.....	.....	330	390	450	510
21	.....	.....	.....	370	430	500	570
22	.....	.....	.....	400	470	560	640
23	.....	.....	.....	440	520	610	710
24	.....	.....	.....	490	570	670	780
25	.....	.....	.....	530	620	740	870

TABLE X
VOLUME TABLE—BEECH

Waha and Cheever, 1903

New York: Based on 485 trees

Merchantable Volume in Standard Railroad Ties

D.B.H. ob, inches	Number of standard ties, 7" x 9" x 8'	D.B.H. ob, inches	Number of standard ties, 7" x 9" x 8'
12	1	22	7
13	2	23	8
14	3	24	9
15	3	25	10
16	3	26	11
17	4	27	11
18	4	28	12
19	5	29	13
20	6	30	14
21	7		

TABLE XI*

TABLE 9.—SHOWING TOTAL HEIGHT, CLEAR LENGTH AND VOLUME FOR DIFFERENT DIAMETERS OF COTTONWOOD GROWING IN MISSISSIPPI BOTTOMS

Diameter Breast High inches	Total height feet	Clear length, feet	Volume board feet [†]
6	58	24	..
7	65	28	..
8	72	31	..
9	78	34	..
10	83	36	..
11	86	38	20
12	93	40	40
13	97	42	60
14	101	44	85
15	105	46	115
16	109	47	145
17	113	48	180
18	116	50	225
19	119	51	275
20	122	52	340
21	125	53	405
22	127	54	480
23	130	54	560
24	132	55	645
25	134	56	735
26	136	56	820
27	138	57	910
28	140	57	1,000
29	141	58	1,090
30	143	58	1,175
31	144	58	1,265
32	146	59	1,360
33	147	59	1,450
34	148	59	1,540
35	149	59	1,635
36	150	59	1,725
37	151	59	1,820

*Compiled by S. J. Record.

†Doyle Rule

TABLE XII.—TAPER TABLE FOR WHITE OAK, AVA, ILLINOIS

D.B.H. Inches	Feet above the Stump										Diameters inside Bark (inches)									
	8	10	12	14	16	20	24	28	30	32	36	40	42							
6	4.6	4.3	4.1	....	....	....	....	....	....	....	....	....	....							
7	5.6	5.1	4.9	....	4.3	....	....	....	....	....	....	....	....							
8	6.4	5.9	5.7	....	5.1	4.4	4.0	....	....	....	....	....	....							
9	7.3	6.8	6.5	6.2	5.9	5.1	4.7	....	....	....	....	....	....							
10	8.1	7.6	7.3	7.0	6.7	5.9	5.5	....	....	....	....	....	....							
11	9.0	8.4	8.1	7.8	7.5	6.7	6.3	....	....	....	....	....	....							
12	9.8	9.2	9.0	8.6	8.4	7.5	7.1	6.1	6.0	....	....	....	....							
13	10.7	10.0	9.7	9.4	9.2	8.3	7.9	6.9	6.8	6.4	....	....	....							
14	11.5	10.9	10.5	10.2	10.0	9.1	8.7	7.8	7.6	7.2	6.8	....	....							
15	12.3	11.7	11.3	10.9	10.9	10.0	9.5	8.6	8.4	8.0	7.6	6.2	....							
16	13.2	12.5	12.1	11.8	11.8	10.8	10.3	9.4	9.2	8.8	8.4	7.0	....							
17	14.0	13.3	12.9	12.6	12.6	11.6	11.1	10.2	10.0	9.6	9.2	7.8	6.3							
18	14.9	14.1	13.7	13.4	13.4	12.4	11.9	11.0	10.8	10.4	10.0	8.6	7.2							
19	15.7	15.0	14.5	14.2	14.1	13.3	12.7	11.8	11.6	11.2	10.8	9.4	8.1							
20	16.6	15.9	15.3	15.0	15.0	14.0	13.5	12.6	12.4	12.0	11.5	10.2	9.0							
21	17.4	16.7	16.1	15.8	16.5	14.7	14.3	13.4	13.2	12.8	12.2	11.0	9.9							
22	18.3	17.5	17.0	16.6	16.6	15.5	15.1	14.2	14.0	13.6	13.0	11.8	10.8							
23	19.1	18.3	17.8	17.5	17.5	16.3	15.9	15.0	14.8	14.4	13.7	12.7	11.7							
24	19.9	19.1	18.6	18.3	18.3	17.1	16.7	15.8	15.6	15.1	14.4	13.5	12.6							
25	20.8	20.0	19.4	19.1	19.1	18.0	17.5	16.6	16.4	15.9	15.2	14.3	13.5							
26	21.7	20.8	20.2	20.0	20.0	18.8	18.3	17.4	17.2	16.5	15.9	15.1	14.4							
27	22.5	21.7	21.1	20.8	20.8	19.6	19.1	18.2	18.0	17.4	16.6	15.6	15.3							
28	23.3	22.5	21.9	21.7	21.7	20.4	19.9	19.0	18.8	18.2	17.4	16.7	16.2							

NOTE.—A taper table shows the diameter inside the bark at specified heights above the stump, the average stump height in this case being taken as two feet. With such a table one can read for a tree with a given diameter breast-high outside the bark (o.b.) its size inside the bark at 8, 10, 12, 14, 16, etc., feet above the stump, and look up the board-foot contents of a certain length log by any log rule. It also affords the data for computing the contents of trees in cubic feet or estimating top diameters of railroad ties. Volume tables in board-foot or cubic-foot units can also be easily made from good taper tables.

TABLE XIII.—TAPER TABLE FOR BLACK OAK, AVA, ILLINOIS

D.B.H. Inches	Feet above the Stump											42
	8	10	12	14	16	20	24	28	30	32	36	40
Diameters inside Bark (inches)												
8	7.2	7.0	6.7	6.4	6.0	5.5	.....	.....	.....	.....	.....	.....
9	8.1	7.8	7.5	7.2	6.9	6.3	.....	.....	.....	.....	.....	.....
10	8.9	8.6	8.3	8.0	7.7	7.1	6.5	.....	.....	.....	.....	.....
11	9.7	9.4	9.1	8.8	8.5	7.9	7.3	6.7	.....	.....	.....	.....
12	10.5	10.2	10.0	9.6	9.3	8.7	8.1	7.5	.....	.....	.....	.....
13	11.3	11.0	10.7	10.4	10.1	9.5	8.9	8.3	8.1	.....	.....	.....
14	12.1	11.8	11.6	11.2	11.0	10.3	9.7	9.1	8.9	8.6	.....	.....
15	12.9	12.6	12.4	12.0	11.7	11.1	10.5	10.0	9.7	9.4	.....	.....
16	13.7	13.4	13.2	12.8	12.5	12.0	11.4	10.8	10.5	10.2	9.6	.....
17	14.6	14.2	14.0	13.6	13.3	12.8	12.2	11.6	11.3	11.0	10.4	.....
18	15.4	15.0	14.8	14.4	14.2	13.6	13.0	12.4	12.1	11.8	11.2	.....
19	16.2	15.8	15.6	15.2	15.0	14.4	13.8	13.2	13.0	12.6	12.0	11.4
20	17.0	16.6	16.4	16.1	15.8	15.2	14.6	14.0	13.8	13.4	12.8	12.2
21	17.8	17.5	17.2	16.9	16.6	16.0	15.4	14.8	14.6	14.2	13.7	13.1
22	18.6	18.3	18.0	17.7	17.4	16.8	16.2	15.6	15.4	15.0	14.5	13.9
23	19.4	19.1	18.8	18.5	18.2	17.6	17.0	16.4	16.2	15.8	15.3	14.7
24	20.3	19.9	19.6	19.3	19.0	18.4	17.9	17.2	17.0	16.6	16.1	15.5
25	21.1	20.7	20.4	20.1	19.8	19.2	18.7	18.0	17.8	17.4	17.0	16.3
26	21.9	21.6	21.3	20.9	20.7	20.1	19.5	18.9	18.6	18.3	17.8	17.1
27	22.7	22.4	22.1	21.7	21.5	20.9	20.3	19.7	19.4	19.1	18.6	18.0
28	23.5	23.2	22.9	22.5	22.3	21.7	21.1	20.5	20.2	20.0	19.4	18.8
29	24.3	24.0	23.7	23.3	23.1	22.5	21.9	21.3	21.0	20.8	20.2	19.4
30	25.1	25.8	24.5	24.2	24.0	23.4	22.8	22.2	21.9	21.6	21.1	20.5

TABLE XIV

BLACK OAK GROWTH-TABLE, SHOWING TOTAL HEIGHT, AGE ON STUMP, AND
VOLUME IN CUBIC FEET AND BOARD FEET BASED ON
D. B. H., AVA, ILLINOIS

D.B.H. inches	Age on stump, years	Total height, feet	Total volume, cu. ft.	Merchant- able	Volume in board feet, (Ava table*)	No. of trees measured
6	45	35				
7	51	39				
8	56	43	7.00	4.00	20	1
9	62	46	7.50	6.00	39	1
10	67	50	11.50	8.00	51	1
11	73	53	15.00	11.00	64	1
12	76	57	19.50	14.50	83	1
13	79	60	25.00	18.50	103	1
14	83	64	30.00	22.50	129	6
15	86	67	35.50	26.00	154	6
16	89	70	42.50	30.00	178	7
17	93	72	49.50	35.50	215	7
18	96	74	57.50	41.00	263	3
19	99	76	65.00	47.50	298	8
20	102	78	72.50	54.00	344	6
21	106	80	80.00	61.00	394	4
22	109	81	87.50	68.00	455	4
23	112	82	95.00	75.00	506	2
24	114	83	103.00	82.50	560	2
25	117	84	110.00	90.00	621	1
26	119	84	117.50	97.50	695	1
27	121	84	125.00	107.00	770	1
28	123	84	137.50	117.00	845	1
29	125	84	157.50	127.00	920	2
30	127	85	178.00	140.00	1,000	1
						Tot. 68

*The results in column 6 were obtained from averages of trees scaled by the Maine rule.

TABLE XV

WHITE OAK GROWTH-TABLE, SHOWING TOTAL HEIGHT, AGE ON STUMP,
AND VOLUME IN CUBIC AND BOARD FEET BASED ON D. B. H.
AVA, ILLINOIS

D.B.H. inches	Age on stump years	Total height	Volume in cubic feet		Board feet* (Ava table)	Number of trees measured
			Total	Merchant- able		
6	60	34	7.5	4	..	2
7	63	39	8.5	5.5	5	4
8	66	44.5	9.5	6.5	9	4
9	70	48	11.0	7.5	18	7
10	74	52	12.5	8.5	28	6
11	80	54.5	14.5	10.5	41	10
12	86	57.5	16.5	12.5	57	8
13	94	59.5	20.5	15	77	1
14	103	62	25.0	18	97	1
15	111	64	32.0	23	120	1
16	120	66	39.0	27.5	147	2
17	130	68	46.5	33	172	4
18	140	69.5	54.0	38	222	3
19	150	71	61.0	43	245	0
20	160	72.5	68.5	49	285	2
21	170	73.5	76.5	55	323	4
22	180	74.5	82.5	61.5	366	2
23	191	75.5	90.5	68	413	2
24	201	76.5	99.0	75	464	1
25	211	77.5	107.0	82	520	3
26	222	78	116.0	89	582	1
						Tot. 68

*The results in column 6 were obtained from averages of trees scaled by the Maine rule.

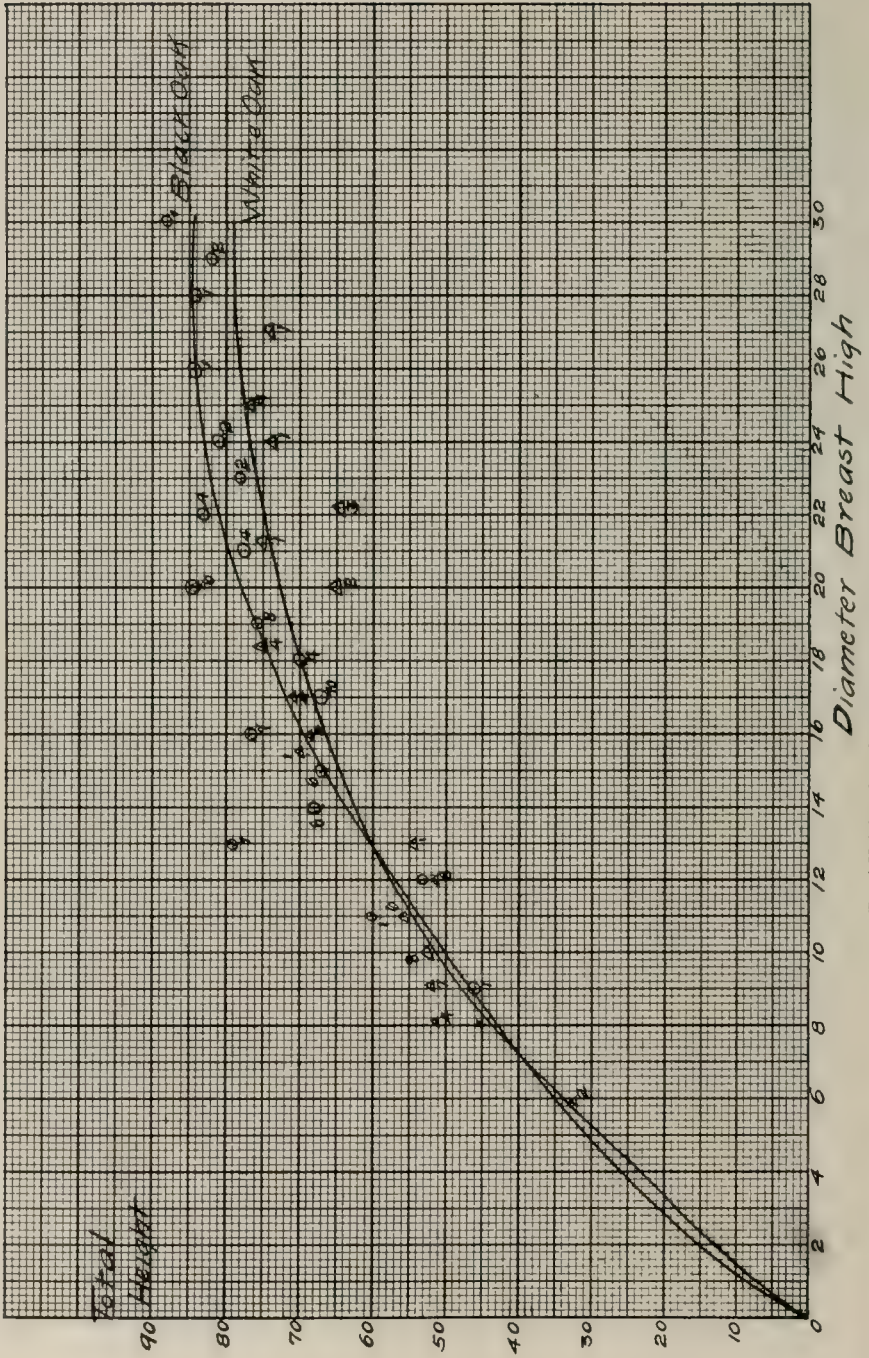
TABLE XVI
TAPER TABLE FOR BLACK OAK (ALL-AGED STAND)
READ FROM GRAPH V

Age years	Diameter on stump inside bark, inches	Diameter breast- high out- side bark, inches	Diameter at 8 ft. above stump in- side bark, inches	Diameter at 16 ft. above stump	Diameter at 24 ft. above stump	Diameter at 32 ft. above stump	Diameter at 40 ft. above stump	Volume in cubic feet
10	.6	0	0	0	0	0	0	
20	2.0	1.5	1.0	0	0	0	0	.112
30	3.3	3.2	2.4	1.3	.2	0	0	.88
40	5.0	5.1	4.0	3.0	1.9	.7	0	1.70
50	6.6	6.8	5.7	4.6	2.6	2.5	0	3.72
60	8.4	8.6	7.5	6.2	5.1	4.3	2.0	7.71
70	10.2	10.5	9.2	8.0	6.8	6.0	4.4	12.75
80	13.0	13.2	11.4	10.2	9.0	8.1	6.8	21.31
90	16.2	16.2	13.9	12.7	11.6	10.4	9.2	33.51
100	19.2	19.2	16.2	15.1	14.1	12.8	11.8	48.3
110	22.0	22.1	18.8	17.7	16.4	15.4	14.2	67.2
120	24.5	24.9	21.2	19.8	18.6	17.4	16.3	83.9
130	26.2	26.6	22.8	21.6	20.4	19.3	18.2	98.56

TABLE XVII
TAPER TABLE FOR WHITE OAK (ALL-AGED STAND)
READ FROM GRAPH VI

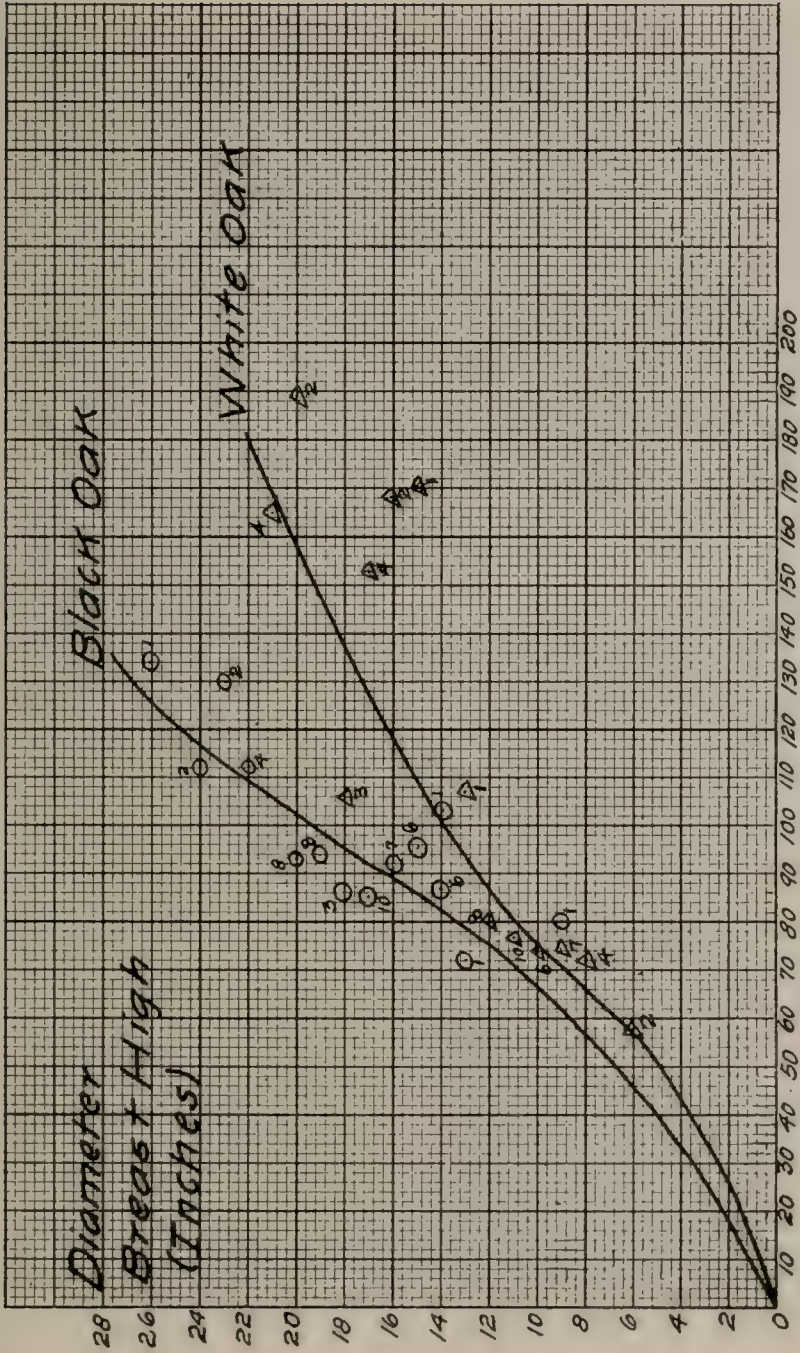
Age years	Diameter on stump inside bark, inches	Diameter breast- high out- side bark, inches	Diameter 8 ft. above stump	Diameter 16 ft. above stump	Diameter 24 ft. above stump	Diameter 32 ft. above stump	Diameter 40 ft. above stump	Volume in cubic feet
10	.2	0	0	0	0	0	0	
20	.8	0	0	0	0	0	0	
30	1.7	1.0	0	0	0	0	0	
40	3.0	2.2	1.0	0	0	0	0	
50	4.8	3.8	2.7	1.6	0	0	0	.96
60	6.8	6.2	4.6	3.6	2.3	.4	0	2.61
70	8.8	9.0	7.3	5.9	4.7	2.7	1.2	7.32
80	11.6	10.1	9.0	7.5	6.3	4.4	3.0	11.79
90	13.0	12.6	10.2	8.8	7.5	5.9	4.2	15.96
100	14.1	13.8	11.3	9.8	8.4	7.0	5.2	20.32
110	15.3	14.9	12.2	10.8	9.4	8.0	6.2	24.16
120	16.3	16.0	13.1	11.7	10.2	8.8	7.1	31.3
130	17.3	17.0	14.0	12.6	11.1	9.6	7.9	32.7
140	18.2	18.0	14.9	13.4	11.9	10.4	8.6	37.65
150	19.2	18.9	15.7	14.2	12.7	11.2	9.4	42.03
160	20.2	19.9	16.6	15.0	13.5	12.0	10.2	47.24
170	21.1	21.0	17.4	15.8	14.3	12.8	11.0	52.52
180	22.0	21.9	18.3	16.6	15.1	13.6	11.8	58.26
190	22.8	22.9	19.1	17.4	15.8	14.3	12.7	63.80
200	23.8	23.8	19.9	18.2	16.5	15.1	13.5	68.90
210	24.7	24.7	20.7	19.1	17.3	15.8	14.3	73.35
220	25.5	25.5	21.5	19.9	18.1	16.4	15.0	82.58

GRAPH I



Total Heights, based on D.B.H., for White and Black Oak.

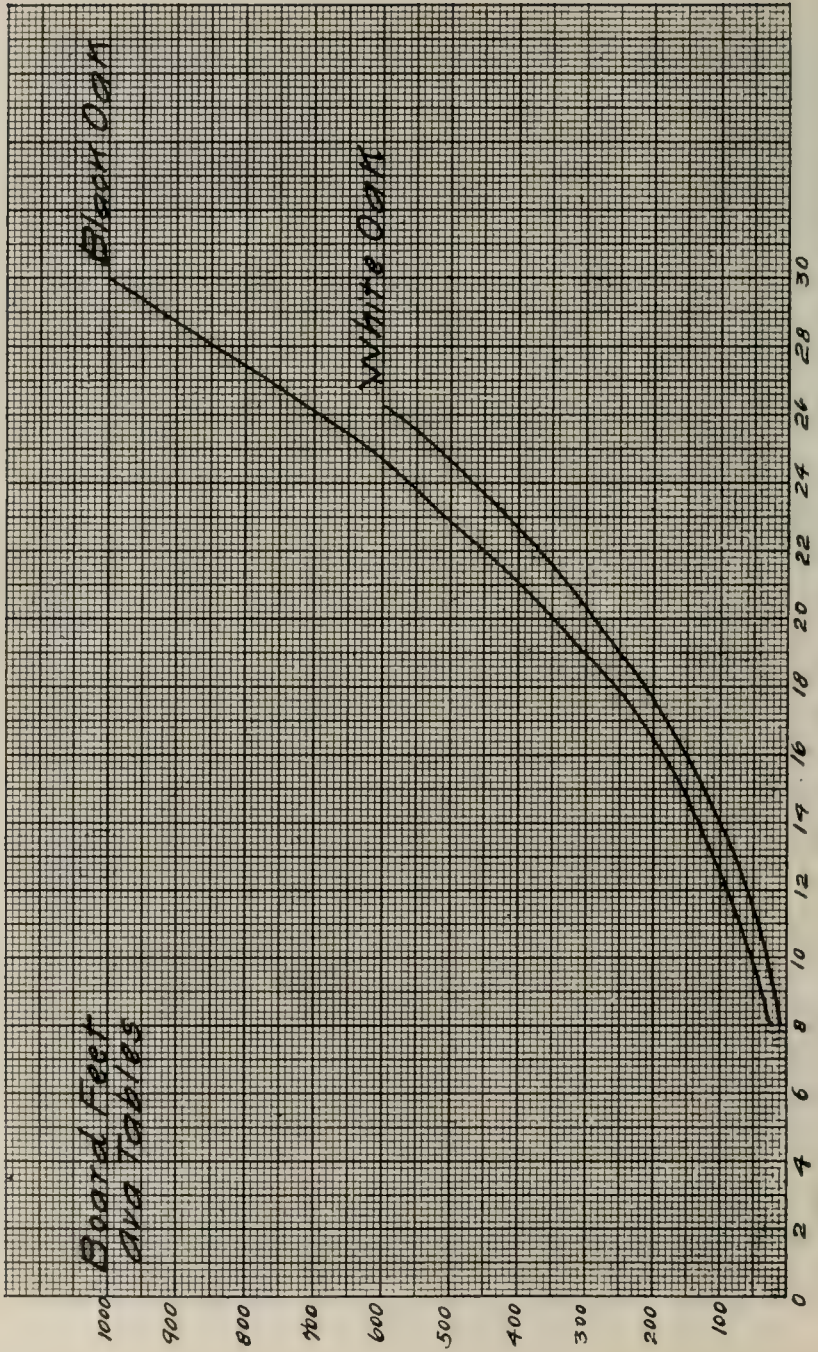
GRAPH II



Age on Stump (Years)

Diameter Growth outside Bark at D.B.H. for White and Black Oak.

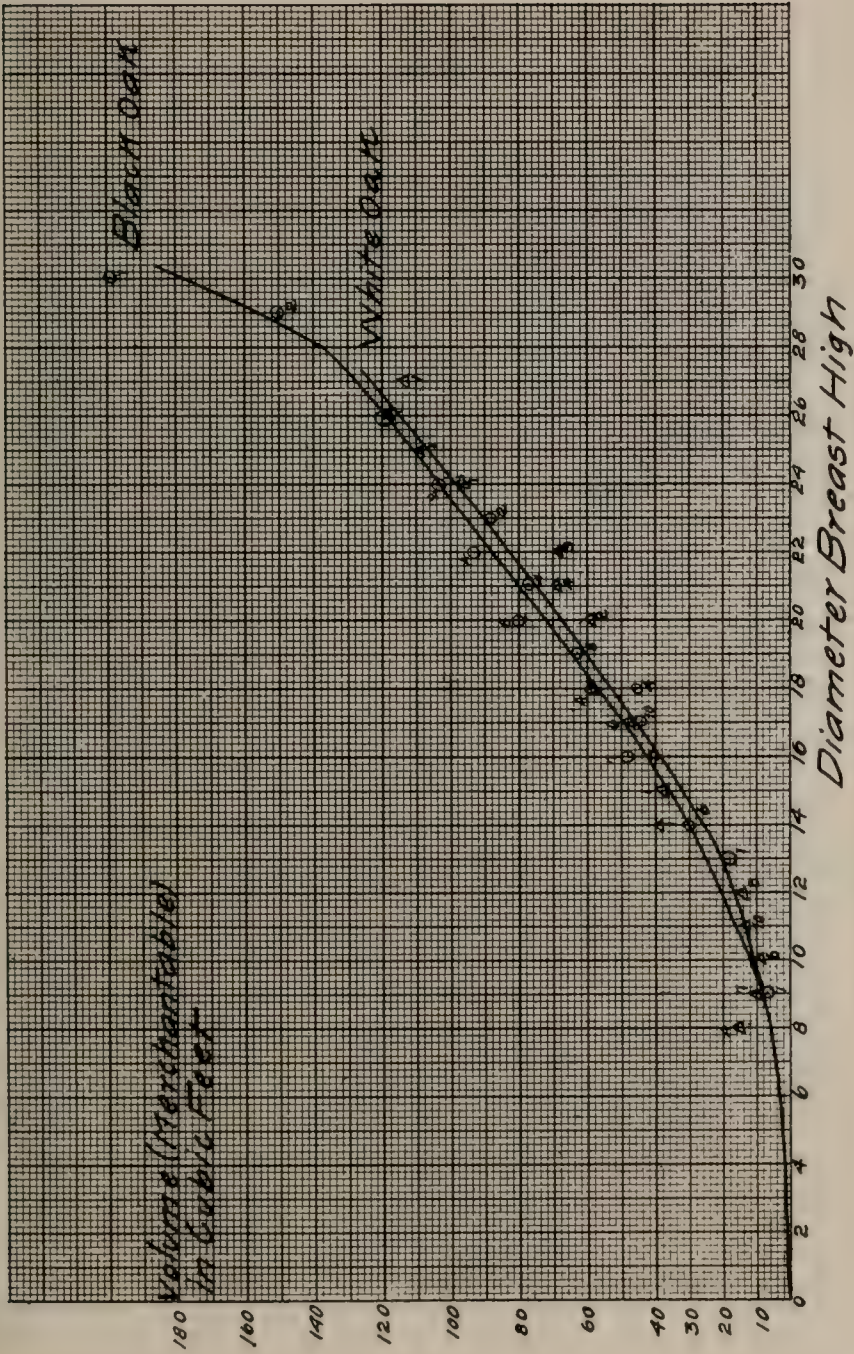
GRAPH III



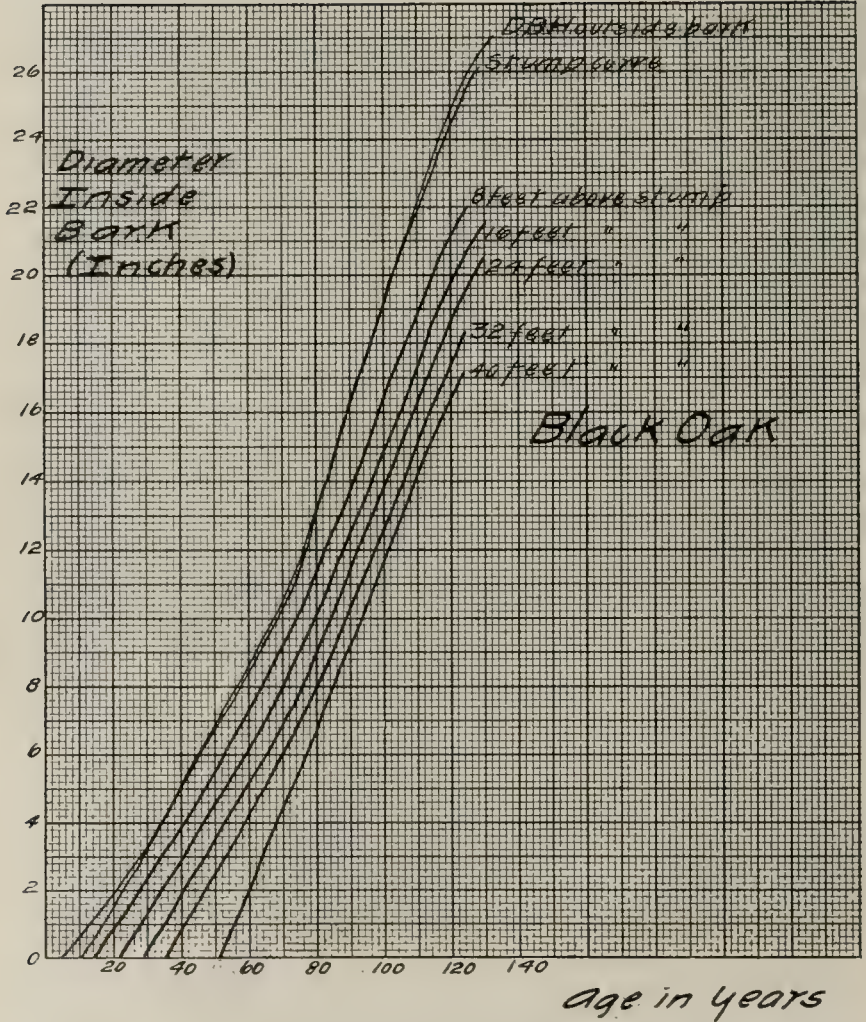
Diameter Breast High (Inches)

Volumes in Board Feet, based on D.B.H., for White and Black Oak (Maine Rule).

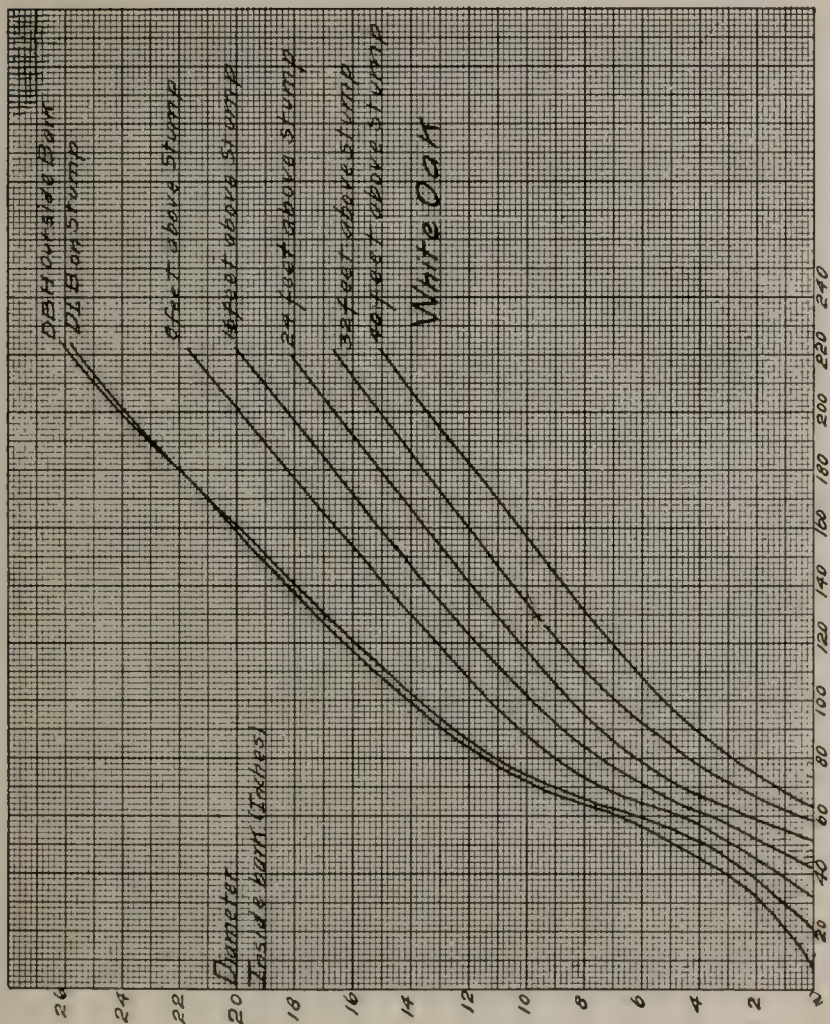
GRAPH IV



GRAPH V



Diameter Growth inside Bark for Black Oak at different Heights.



Diameter Growth inside Bark for White Oak at different Heights.

PLATE LXXIV



Dry oak-hickory forest, Clear Creek region, Jonesboro quadrangle. The dense growth of grass in the openings means that there is too much light, and it makes fire protection difficult.

PLATE LXXV



Cut-over land in the Caney Creek region, Jonesboro quadrangle, Union county. The former stand was made up of white oak, beech, and tulip-tree. Notice the rank growth of weeds which greatly increases the liability to fire.

PLATE LXXVI



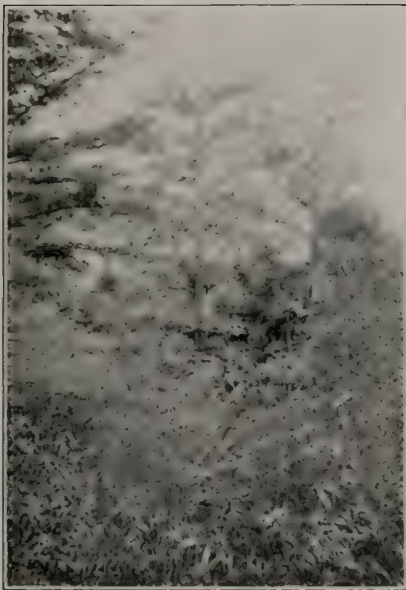
Narrow valley in Alexander county at the southern end of Jonesboro quadrangle, showing timber on the hills.

PLATE LXXVII



The valley of Caney Creek, Union county, northern edge of Jonesboro quadrangle.

PLATE LXXVIII



Cypress swamp.



Limestone outcrop, Ava, Jackson county.

PLATE LXXIX



Bald cypress trees showing swollen bases, and three cypress "knees" in the left foreground.
Photo by courtesy of the U. S. Forest Service.



Shortleaf pine at Wolf Lake, Union county, overlooking the Mississippi bottoms.
Photo by Paul J. Sedgwick.



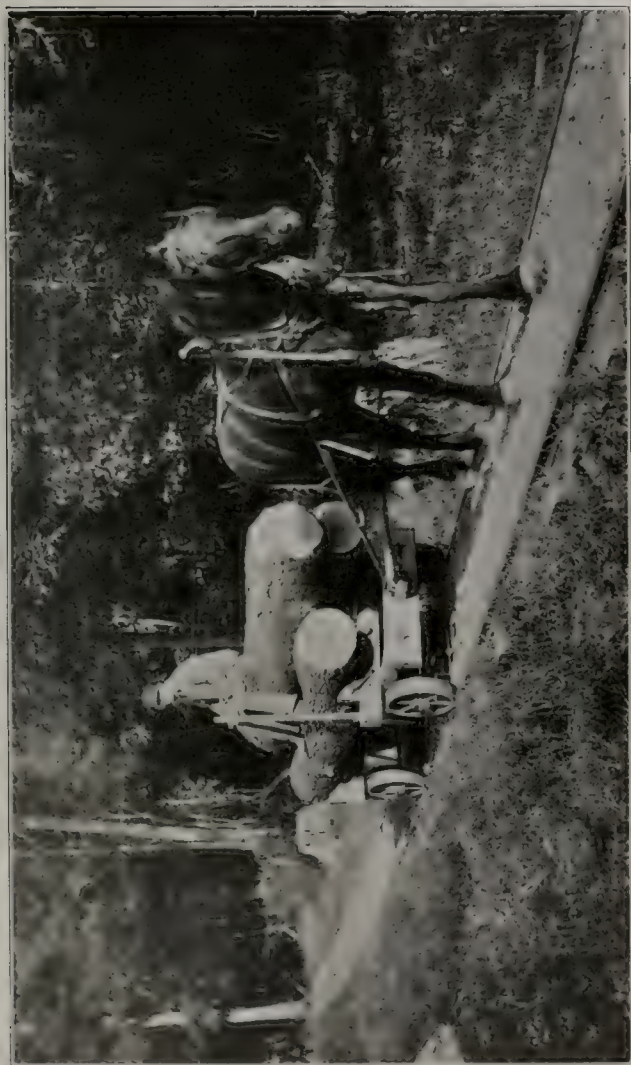
Old house at Wolf Lake, Union county, built of shortleaf pine logs.
Photo by Paul J. Sedgwick.

PLATE LXXXI



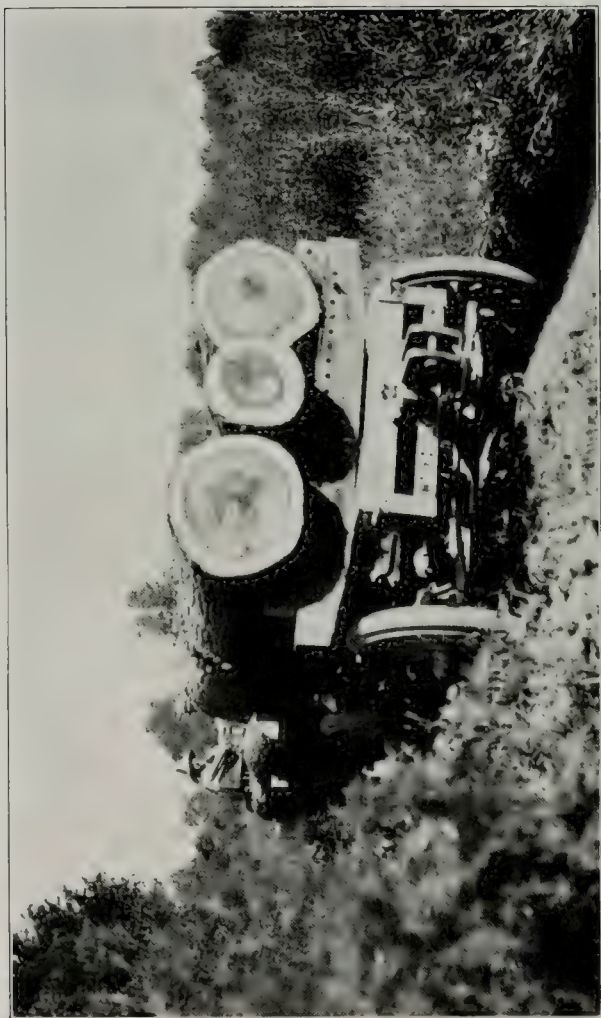
Skidway at Indian Creek, near Murphysboro, Jackson county, where hardwood logs are loaded on tramways.

PLATE LXXXII



Logs going to the mill on a tramway, at Indian Creek, Murphysboro.

PLATE LXXXIII



Hauling logs by motor-truck from bottomlands to mill at Ware, Union county.

PLATE LXXXIV



Tulip-tree, or yellow poplar, log being headed on a log wagon near Ava, by the "cross-haul" method. It is a butt log 20 feet in length, which will scale 500 board feet by the Doyle-Scribner rule.

PLATE LXXXV



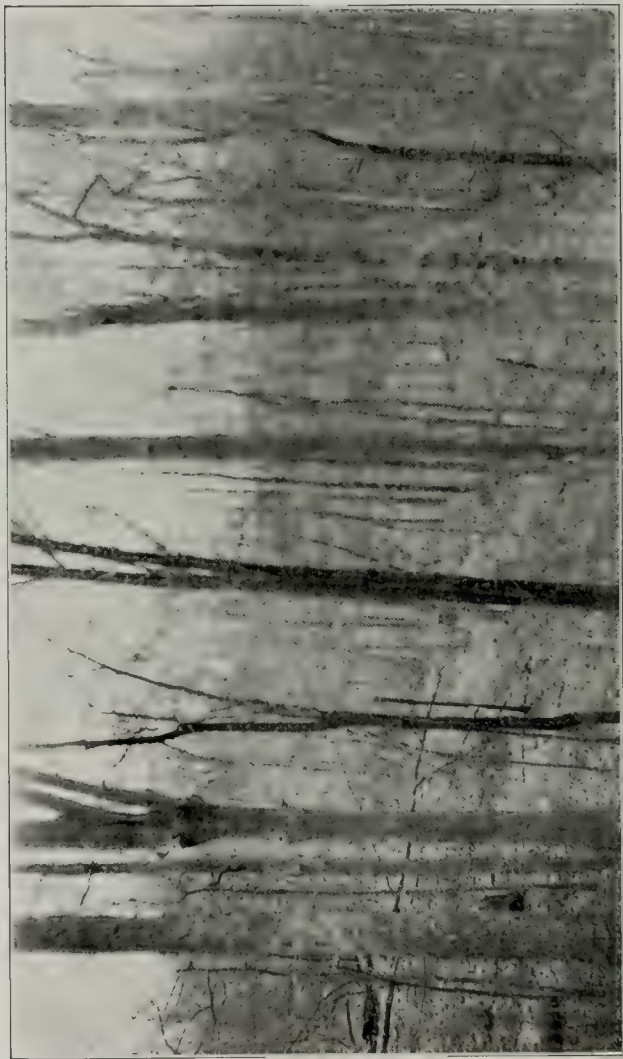
Butt log of a large tulip-tree, or yellow poplar, loaded on a log wagon, or "dray," ready for hauling to the mill at Ava. This log was 20 feet long and would scale 500 feet by the Doyle-Scribner rule.

PLATE LXXXVI



A "tie-hackers' camp" at Alto Pass, Union county. These men are usually financed by a tie contractor.

PLATE LXXXVII



White oak and black oak timber which has been culled for ties. Notice that a fair stand of timber remains which it would pay to protect. Alto Pass, Union county.

PLATE LXXXVIII



A small portable mill on the "Dug Hill" road, Union county, operated by S. A. Morse, who is seen sawing railroad ties from beech logs.

PLATE LXXXIX



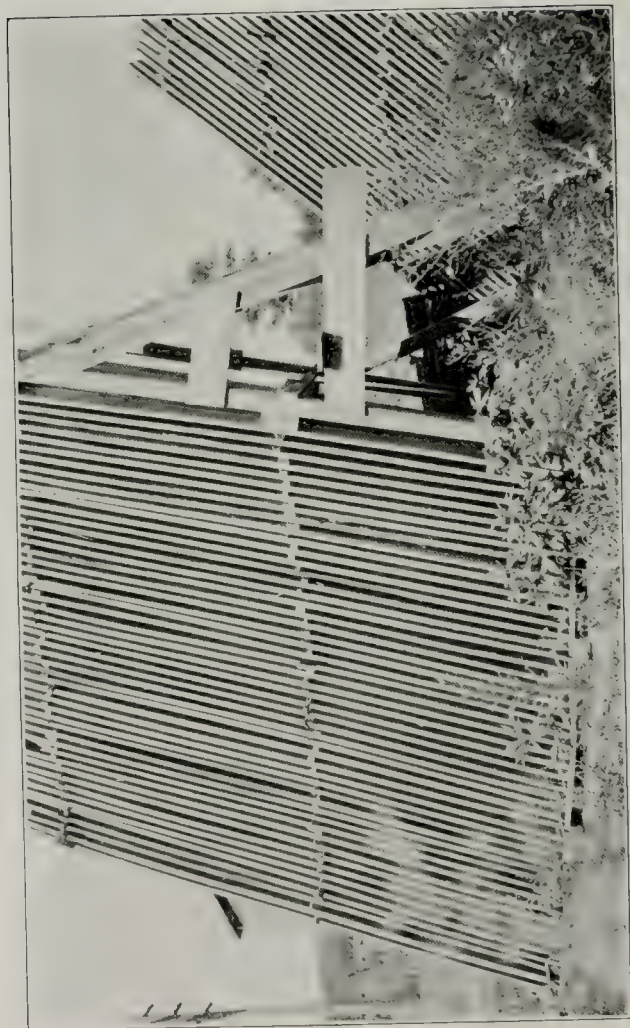
Small portable sawmill near Alto Pass, Union county.
Photo by Paul J. Sedgwick.

PLATE XC



Larger, stationary, sawmill near Indian Creek, Murphysboro, Jackson county.

PLATE XCI



Sawed lumber piled on end, Jonesboro, Union county.

PLATE XCII



Veneer mill of the Fruit-Growers' Package Company, Jonesboro, Union county.

PLATE XCIII



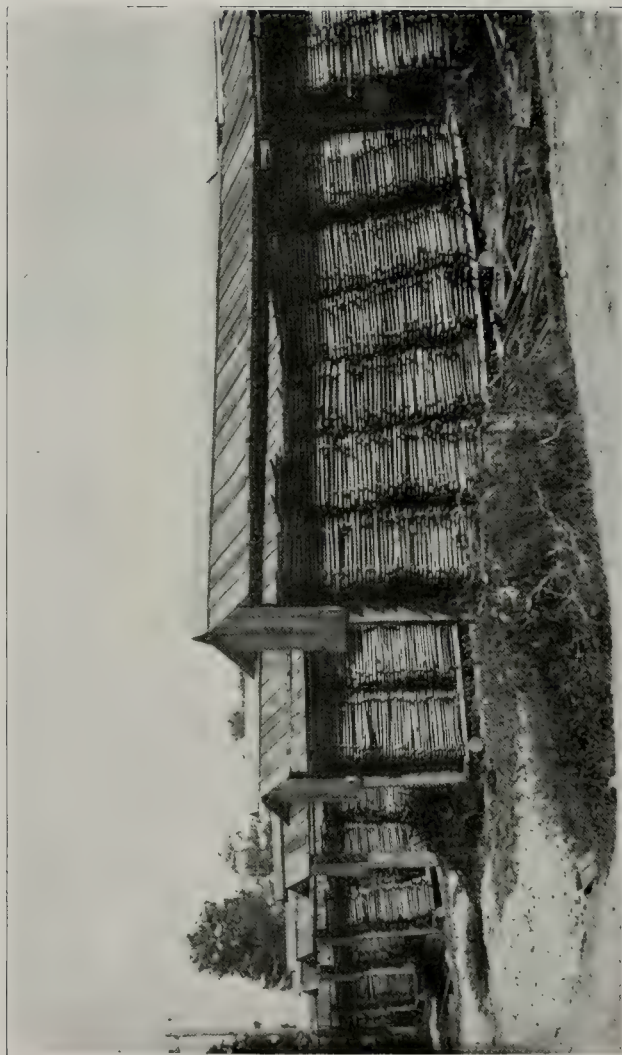
Hardwood logs at a veneer plant ready to be cut up into bolts. Most of these come from bottomlands.

PLATE XCIV



Veneer bolts from the cut-off saw ready to go to the steam boxes for softening before being taken to the rotary veneer-machines.

PLATE XCV



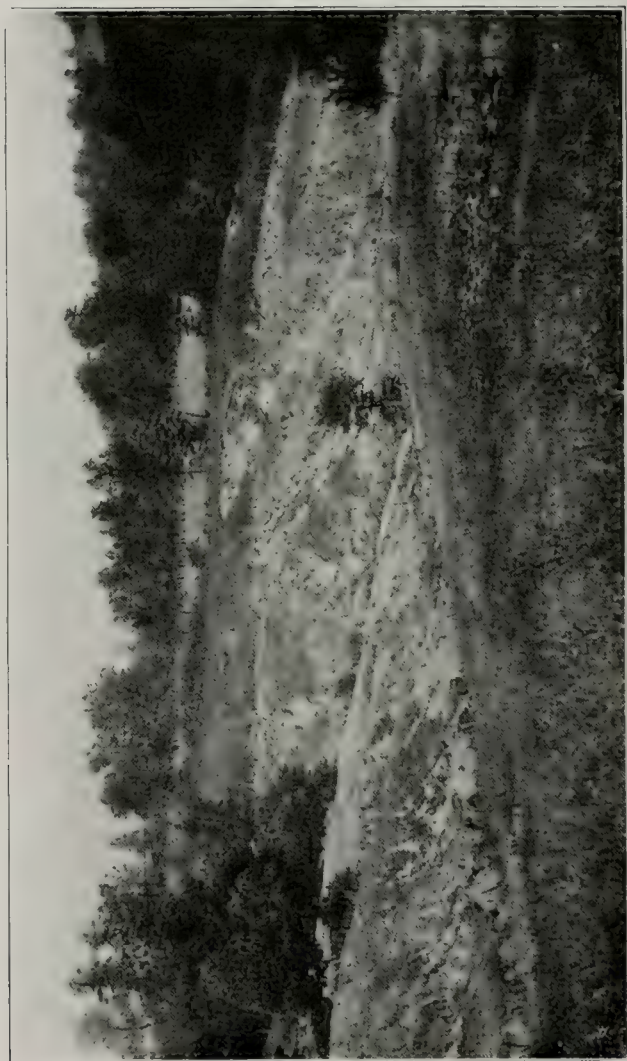
Thin boards, or "shooks," drying under sheds. These will be made up into egg crates.

PLATE XCVI



A battery of three charcoal kilns. These are built of brick, and charcoal is the only product secured.

PLATE XCVII



Erosion on a "forty" in Pomona township, Jackson county.

PLATE XCVIII



Erosion near Alto Pass, Union county.
Photo by Paul J. Sedgwick.

PLATE XCIX



Logging slash left after a logging-and-tie operation. This is typical of the appearance of most cut-over lands.

PLATE C



A burned-over side-slope at Alto Pass, Union county, on cherty soil. Notice the bare appearance of the ground and the fallen tulip-trees, indicating the severity of the fire.





MAP OF TIMBERED AREAS EXTENDING FROM THEBES TO CHESTER, ILLINOIS

LEGEND

UPLAND TYPES

-  Cutover forest, merchantable timber remains
-  No. 1—Stand up to 2000 board feet per acre
-  No. 2—Stand from 2000-5000 board feet per acre
-  No. 4—Stand over 10,000 board feet per acre
-  Short leaf pine

BOTCHLAND TYPES

-  Cutover forest, merchantable timber remains
-  No. 1B—Stand up to 2000 board feet per acre
-  No. 2B—Stand from 2000-5000 board feet per acre
-  No. 4B—Stand over 10,000 board feet per acre
-  No. 1B Cypress—Stand up to 2000 board feet per acre
-  No. 2B Cypress—Stand from 2000-5000 board feet per acre



STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION
DIVISION OF THE
NATURAL HISTORY SURVEY
STEPHEN A. FORBES, Chief

Vol. XIV.

BULLETIN

Article IX.

The Determination of Hydrogen Ion
Concentration in Connection
With Fresh-Water Bio-
logical Studies

BY
VICTOR E. SHELFORD



PRINTED BY AUTHORITY OF THE STATE OF ILLINOIS

URBANA, ILLINOIS
February, 1923

STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION
A. M. SHELTON, *Director*

BOARD OF
NATURAL RESOURCES AND CONSERVATION

A. M. SHELTON, *Chairman*

WILLIAM TRELEASE, *Biology*
JOHN M. COULTER, *Forestry*
EDSON S. BASTIN, *Geology*
WILLIAM A. NOYES, *Chemistry*

JOHN W. ALVORD, *Engineering*
KENDRIC C. BABCOCK, *Representing the*
President of the University of Ill-
nois

THE NATURAL HISTORY SURVEY DIVISION
STEPHEN A. FORBES, *Chief*



PHILLIPS BROS.' PRINT
SPRINGFIELD, ILLINOIS.

CONTENTS

	PAGE
Introduction	379
Methods of determining H ion concentration (pH)	380
The influence of Hydrogen ion concentration on fertilization, development, growth, and survival in water deficient in dissolved oxygen	381
Reactions of fish to differences in hydrogen ion concentrations	385
An examination of certain Illinois waters with special reference to hydro- gen ion concentration	386
General relations of hydrogen ion concentration to other factors	388
Discussion and summary of results	391
Conclusions	392
Acknowledgments	394
Bibliography	394



ARTICLE IX.—*The Determination of Hydrogen Ion Concentration in Connection with Fresh-Water Biological Studies.* BY VICTOR E. SHELFORD.

INTRODUCTION

Generally speaking, the significance of hydrogen ion concentration and its determination are among the most complicated problems confronting students of fresh-water ecology. Determinations of carbon dioxide, "alkalinity," and dissolved oxygen have long been among the means used for ascertaining the suitability of a water for organisms, as well as its suitability for domestic and industrial purposes, but the relations of these properties of a water to each other chemically or to organisms have never been fully investigated.

There is great confusion as to methods of measuring and expressing so-called "alkalinity." It is expressed (*a*) in terms of a carbonate of a predominating alkaline metal—for example, as CaCO_3 ; (*b*) as bound and half-bound CO_2 ; (*c*) as alkali reserve; and (*d*) as buffer value. It is from time to time confused with CO_2 tension, total CO_2 , and the normal acid used. It is not possible to straighten out this confusion. The investigator can only ascertain the methods used by different writers and carefully translate their records and statements into the terms he himself has elected to use.

There is almost as great confusion in the use of terms and methods in connection with hydrogen ion concentration. This grows out of the fact that the turning points of various standard indicators have been referred to as "neutral," notably in the case of phenolphthalein, the turning point of which is decidedly alkaline. There are now improved methods of determining hydrogen ion concentration, including true neutrality. These have been used in the work here reported, which has consisted chiefly of (1) observations on the hydrogen ion concentration over fish breeding-grounds in several Illinois localities, July to June, 1919-20; (2) studies of the reactions of fishes to hydrogen ion concentration; and (3) studies of the effect of different hydrogen ion concentrations on the survival of fishes in water of low oxygen-content. This work has been supplemented by studies by Fenner Stickney on the resistance and reactions of a dragon-fly nymph to various hydrogen ion concentrations and by experiments by Miss Ada Hall on the effect of hydrogen ions in the development of toad and whitefish eggs, carried on under the auspices of the Department of Zoology and of the Graduate School of the University of Illinois. The author's acquaintance with the questions discussed has also been extended by a series of determinations of hydrogen ions in rivers and lakes in the following drainage systems: Puget Sound, Columbia River, Interior Basin, Colorado River, and Arkansas River. These determinations will be published elsewhere.

These studies have been made by the author largely with a view to ascertaining whether or not hydrogen ion determinations give indications of value in the field of animal ecology. The author's answer is in the affirmative. It is accordingly the purpose of this paper to show (1) that hydrogen ion concentration is one of the factors governing the movement and distribution of fishes, its importance on the whole probably equaling that of well-known factors; (2) that breeding places of fish are characterized by differences in hydrogen ion concentration; (3) that hydrogen ion concentration has marked influence on the survival of fishes under adverse conditions.

METHODS OF DETERMINING H ION CONCENTRATION (pH)

The methods in common use are the colorimetric and the electrometric. The former is based on the colors assumed by solutions of various dyes in the presence of various hydrogen ion concentrations. The latter is based on measurement of the differences of the electric potential between the solution to be tested and a hydrogen electrode. In this process it is necessary to bubble hydrogen through the sample, and as this withdraws CO_2 it is not practicable as a field method. It is desirable to dip the apparatus into the mud or water and measure while *in situ*. This might be possible except for the additional fact that the pressure of the hydrogen (gas) must be maintained at one atmosphere, or corrected to this pressure, which renders the use of the electrometric method impracticable in the field. Colorimetric standards may be color charts for rough work or for work on soils—those published in Clark's book ('20) may be purchased separately—but for use in fresh water greater accuracy is necessary. For this purpose "buffer" solutions of known hydrogen ion concentration are placed in hard glass tubes, a standard amount of indicator added, and the tubes sealed up and used for comparison with water samples with the same amount and kind of indicator added. Several firms make such sets of standards, but the range at present is limited, and others must be added for some waters. These additional buffers may be made by a competent chemist. Standardization of buffers electrometrically is quite essential; also the purchased sets must be checked electrometrically at the beginning and end of each series of readings.

Hydrogen ion concentration is expressed as pH—the logarithm of the reciprocal of the normality of free hydrogen ions. The pH scale and relative amounts of free hydrogen ions are as follows:

pH	Acid						Neutral	Alkaline							
	0	1	2	3	4	5		6	7	8	9	10	11	12	13	14
	10000000	1000000	100000	10000	1000	100	10	1	0.1	0.01	0.001	0.0001	0.00001	0.000001	0.0000001

The range to be expected in Illinois waters is about 8.5 to 6.7 for most streams and lakes not contaminated. Streams receiving mine seepage may have much higher hydrogen ion concentrations and still support certain species of fish.

THE INFLUENCE OF HYDROGEN ION CONCENTRATION ON FERTILIZATION, DEVELOPMENT, GROWTH, AND SURVIVAL IN WATER DEFICIENT IN DISSOLVED OXYGEN

1. *Fertilization of fish eggs.*—Miss Hall found that when oxygen is 4 c.c. per liter fertilization of the eggs of the whitefish takes place equally well in acid, neutral, and alkaline waters. When oxygen is lower (2.9 c.c. per liter) pH 6.2-6.6 is more favorable to fertilization than 7.0-8.4. This relation is quite inexplicably the reverse of what would be expected by comparison with other relations to oxygen.

2. *Development.*—Miss Hall showed that in the toad and whitefish the early cleavage and gastrulation period is most sensitive to hydrogen ion concentration and low oxygen. She further showed that early death or retarded development occurred in both toad and whitefish embryos with pH 6.2 and O_2 about 1 c. c. per liter. In the case of the whitefish, still lower oxygens gave little difference correlated with pH. The experiments with sufficient oxygen indicate that pH 7.0 is near the maximum H ion concentration which permits best development. Even so high a concentration is probably not common on fish breeding-grounds in Illinois waters. Higher concentrations, to pH 6.2, show interference with development, hatching, or length of life. That acid interferes with development was demonstrated by Loeb in 1898, and this having been found generally true, of marine animals at least, the demonstration has become a class experiment with marine forms.

3. *Survival.*—The influence of hydrogen ion concentration on the survival of fishes in low-oxygen water is shown in Tables I-IV.

TABLE I

Showing the effect of hydrogen ion concentration on the survival of rock bass in low-oxygen water, August, 1918.

Number of fish	Weight gm.	Survival in min.	pH	O ₂ in c. c. per liter	Temp., deg. C.
<i>a</i>	10	43	6.0	.42	16
<i>b</i>	10	55	6.5	.22	16
<i>c</i>	11.5	50	6.2	.38	16
<i>d</i>	14.5	1500+	6.5	.79	16
<i>e</i>	16	71	6.1	.70	16
<i>f</i>	18	350	6.5	.79	16
<i>g</i>	18	60	6.2	.68	16
<i>h</i>	21	55	6.5	.42	16
<i>i</i>	28	45	6.3	.23	16
<i>j</i>	138	124	6.0	.72	16

TABLE II

Showing the effect of hydrogen ion concentration on the survival of large-mouthed black bass in low-oxygen water, January, 1921.

Number of fish	Av. weight gm.	Survival in min.	pH	O ₂ c. c.	Temp., deg. C.
<i>a</i> {	6 346	84	8.6	.18	13.5
	6 287	62	6.5	.18	13.5
<i>b</i> {	7 275	64	8.5	.055	13.5
	6 285	47	6.2	.06	13.5
<i>c</i> {	2 255	70	8.5	.06	13.5
	12 328	63	7.6	.06	13.5
	10 320	50	6.2	.06	13.5

Comparing individuals *a*, *b*, and *c* (Table I) it is evident that a decrease of .5 on the pH scale is more important than one of .20 c.c. in O₂ and that a decrease of .3 on the pH scale equals in effect a difference of .46 c.c. in oxygen. Furthermore, fish *c* was heavier than *a* or *b*, and the larger fish usually live longest. Fishes *f* and *g* show a striking differ-

ence in survival when both pH and O_2 are moved in the unfavorable direction. Fishes *h* and *i* are similar to *f* and *g*, but the 28-gram fish (*i*) should have lived longer considering its larger size.

Turning to Table II, group *a* shows that the average time-survival is greater at pH 8.6 than at 6.5, but the difference in weight would operate to exaggerate this. However, the same result is shown in group *b*, where both oxygen and size of fish would operate to reverse the result. Furthermore, group *c*, with fish-weight standing on the whole so as to reverse the result, shows a progressive decrease in survival-time with increase of hydrogen ion concentration.

TABLE III

Showing the effect of hydrogen ion concentration on the survival of bluegills in low-oxygen water. December, 1920, and January, 1921.

Number of fish	Av. weight gm.	Av. survival in min.	pH	O_2 , c. c. per l.	Temp., deg. C.
<i>a</i> {	4 11±	*21+	7.25	.12	13
	4 11±	†21+	8.85	.12	13
<i>b</i> {	4 11±	‡60	8.0	.12	13
	4 11±	§47	8.8	.12	13
<i>c</i> {	5 14.5	15	6.4	.12	13
	6 16	30	8.8	.12	13
<i>d</i> {	6 11	31	8.8	.12	13
	4 11	23	6.5	.12	13
	4 11.5	18	6.2	.12	13
<i>e</i> {	13 12.3	8	8.5	.06	13.5
	15 11.8	27	6.5	.06	13.5

* O. K. at 21 minutes. † Anaesthetized at 21 minutes.

‡ All anaesthetized at 21 minutes. § Two anaesthetized at 21 minutes.

Table III shows results with bluegills. Groups *a* and *b* are self-explanatory. Group *c* shows survival one-half as long at the low pH as at the high. Group *d* shows a progressive shortening of life as pH is lowered. Group *e* suggests that with very low oxygen, pH 6.5 is more favorable than 8.5. The work of Wells and Hall (Table IV) shows similar results with different species.

TABLE IV

Showing the relation of hydrogen ions (CO_2 added) and oxygen to the survival of fishes. Taken from the work of authors indicated.

Author	Species	Wt. in gm.	Survival in min.	pH	O_2 c. c. per liter	Survival time per gram
Wells	<i>Ambloplites rupestris</i>	± 2.0	22	6.6*	.1-.15	10.9
		± 2.0	46	7.0*	.1-.15	20.2
		± 2.0	140	7.7*	.1-.15	62.5
Wells	<i>Notropis cornutus</i>	.6-.8	15	6.6*	.1-.15	25
		.6-.8	195	7.8*	.1-.15	246
Hall	<i>Coregonus clupeiformis</i> at hatching	.....	148	6.3	.1	
		.....	225	9.0	.1	
		.....	240	6.3	.1	
		.....	300	9.0	.1	

* pH calculated.

Powers ('22) has shown that marine fishes require more O_2 at high hydrogen ion concentrations. Thus, in general, the unfavorable effect attributed to low oxygen is partly due to the pH which accompanies it, and this depends largely on the amount of carbonates in the water. The hydrogen ion concentrations which many workers have considered that they were using when acid was added to distilled water have not been attained because of the carbonates present. It has been customary to regard distilled water as essentially free from salts, especially carbonates. Wells ('15) stated that he conducted experiments in distilled water which contained no salts. Later he showed that it had a conductivity of 600×10^{-7} which suggests $\pm .0005$ N solution of carbonates, which is now known to be approximately the carbonate content of distilled water from the source where he obtained his. He did not have anything like the H ion concentration he assumed, either in the killing or gradient experiments. If no salt had been present the pH of his ".000075 H_2SO_4 " would have been between 4.0 and 5.0, which would have quickly killed the fish. An unfortunate loose statement ('15, p. 253) that "fresh-water fishes * * * cannot live normally in neutral [he used the term neutrality for the turning point of phenolphthalein, which as he used it is pH 8.0] or alkaline water caused misunderstanding. In fact, most fresh waters of the Eastern United States are alkaline, and most fresh-water animals live in such waters. The facts were that in water with pH 8.0+ the particular species with which he worked became sluggish and were unsuitable for behavior studies, or died in higher hydroxyl ion concentrations. The concentrations in which he killed the fish were probably only titrated with standard acid, and therefore it is not possible to state what the pH may have been.

TABLE V*

Showing the range of hydrogen ion concentrations entered and selected by several species of fish. The fishes were confined in a long narrow tank differing in hydrogen ion concentration at the two ends. Ordinarily they did not swim the entire length of the tank, but moved back and forth, turning at definite points, and finally coming to rest. These turning and resting points differed in different experiments. (see column headings) of the same series. The upper figures of each couplet show the pH range within which the fishes came to rest; the lower figures of each couplet give the mean points of turning back when headed toward higher or lower pH, and the mean columns give the average pH content at the resting points selected. The third column from the right shows for all experiments the mean pH of the selections made. The second column from the right gives merely the maximum and minimum of the upper figures of the couplets opposite. Aerated water was deep well water aerated. (Species nomenclature after Forbes and Richardson.)

Number of experiments and species used	Aerated water H ₂ SO ₄		Aerated water HCl		Boiled water CO Na ₂ CO ₃		Boiled water HCl Na ₂ CO ₃		Rain-water CO ₂		Distilled water Na ₂ CO ₃ HCl		Distilled water Na ₂ CO ₃		Distilled water HCl and cad- mium and sodium chlorides Fatal		Mean of selections	Extremes selected	Extreme range, mean in pa- renthesis Summary	
	Mean		Mean		Mean		Mean		Mean		Mean		Mean		Mean					
(15) <i>Lepomis humilis</i>	7.4	7.8-7.0 7.4-7.3	7.2	7.9-7.0 7.4-6.8					7.1	7.6-6.9	7.1	7.3-6.8					7.2	7.9-7.0	7.6 (7.2)	6.8
(12) <i>Micropterus salmoides</i>	7.2	7.6-7.1 7.3	7.5	7.6-7.5 7.8-7.0							7.1	7.5-6.9	7.5	7.8-7.1 7.9-6.7			7.3	7.8-7.1	7.9 (7.3)	6.7
(15) <i>Micropterus dolomieu</i>	7.2	8.0-6.9 7.8-7.6	7.1	7.1-6.6	8.0	8.1-7.1	7.4	8.2-6.8 7.6-6.6	7.4	7.0		7.8-6.8	7.8	8.2-7.5			7.4	8.2-6.6	8.2 (7.4)	6.6
(17) <i>Ambloplites rupestris</i>	7.4	7.8-7.1 7.3-7.2	7.7	7.8-6.8 7.5-7.4	7.5	7.7-7.4 7.0	7.1	8.0-6.5						7.9-7.3			7.4	7.8-6.8	8.0 (7.3)	6.5
(12) <i>Abramis crysoleucas</i>	7.2	7.3-7.1 7.2-6.8	7.4	7.5-7.3 7.5-7.0									8.2	8.3-7.2	7.1	7.3-6.8	7.4	8.2-7.1	8.3 (7.5)	6.8
(13) <i>Lepomis megalotis</i>	7.3	7.8-7.0 7.4-7.3			7.3	7.3-7.2 7.8-7.0			7.6	7.2			7.4	7.6-6.8	7.2	8.2-7.1	7.4	7.8-7.0	8.2 (7.5)	6.8
(6) <i>Lepomis cyanellus</i>	7.2	7.7-7.1 7.7-7.4							7.6	6.8	7.4	8.0-7.1		7.0-6.8			7.4	7.7-7.1	8.0 (7.4)	6.8
(1) <i>Notropis umbratilis</i>			7.5	7.6-7.2													7.5		7.6 (7.5)	7.4
(10) <i>Pimephales notatus</i>	7.5	7.7-7.5 7.2	7.7	7.6-7.2			8.2	8.4-8.0			7.6	7.8-7.1	7.8	8.0-7.4			7.6	8.2-7.5	8.4 (7.75)	7.1
(13) <i>Notropis cornutus</i>					8.2	8.1-8.2 8.4-7.1	7.4	8.3-7.0									7.8	8.4-7.4	8.4 (7.7)	7.0
(12) <i>Notropis whippitii</i>	7.8	7.9-7.7 8.0-7.3			8.2	8.4-7.6 8.4-7.6											7.9	8.4-7.6	8.4 (7.85)	7.3

*The movements on which this table is based were graphed according to a method used by Wells (15), and by the author in previous papers, one of them being Article VI of Vol. XI (1917) of this series, and in articles cited therein. Various types of irregularity in the figures of the table are illustrated by the following examples. In the case of *Lepomis humilis*, first double column, the figures 7.2 and 7.6, but it is the average of a number of selections not recorded in the table; in the fifth and sixth double columns no range in selection is shown because only one or two experiments were made in the type of water indicated, but the fishes clearly selected 7.1 as the resting point as shown in the mean column. In the case of *Lepomis cyanellus*, fifth double column, intended to swim back and forth between the extremes indicated. Inspection of the graphs in articles referred to will facilitate an understanding of this table.

sur

We

We

Hal

hy

att

an

hy

the

att

reg

W

con

10

kn

fre

the

ex

H

qu

th

us

wl

in

lir

we

he

or

in

ac

be

It seems abundantly demonstrated that various fresh-water fishes will live in pH 9.0. This is shown by the work of Miss Hall on whitefish and by the observation of Garrey ('16) in connection with the St. Louis city water. The resistance of forms other than fish, especially stagnant water bottom-forms may be great. Stickney ('22) found that a dragon-fly nymph, *Libellula pulchella*, lived in very high H ion concentrations. It tolerated pH 1.0 for 12 hours or more. Miss Hall found toads' eggs very resistant as compared with those of whitefish.

REACTIONS OF FISH TO DIFFERENCES IN HYDROGEN ION CONCENTRATIONS

A large series of experiments was conducted by the author* with ten species of fish and a number of types of water; aerated well-water, boiled water, distilled water, rain-water, etc. The results are given in Table V and in Figure 1. In nearly all cases the fishes reacted definitely to differences. With any given temperature, salt content, etc., they usually behaved consistently, and with any one set of conditions could be depended on to select a given hydrogen ion concentration; but as conditions were varied and the number of readings increased the results varied and were as represented in Table V and Figure 1. The selections tend to fall in two or three places, which with a larger number of readings would probably be reduced to one maximum. Each species will be seen to have a definite range which differs from every other species—as shown by the polygons. All figures run higher with the Na_2CO_3 . An average of approximately twelve experiments were run with each species (the exact number is given in Table V). Fishes accustomed to live in clear open waters, especially the minnows, select the lower hydrogen ion concentrations. It is evident from the range of concentrations selected by them that all these species might be found in the same small stream during non-critical periods. The order in which the species arrange themselves corresponds to the frequency of their occurrence in the bodies of water mentioned (Fig. 1).

The range selected by each species is rather wide, though with a few exceptions the fishes show unmistakable evidences of reacting. Some of the reasons for the broken character of the curves, irregularities, wide range selected, and variation from time to time are as follows: (1) differences in salt content of the water, both experimental differences and those due to differences in aeration in storage reservoirs; (2) difference in steepness of the gradient—a difference of 6.5 to 8.2 would not be encountered in so short a distance in nature.

The following additional reactions have been estimated from published graphs and by calculations by one of the equations of Greenfield and Baker ('20), which are presented on page 388.

* For methods see Bul. Ill. State Lab. Nat. Hist., Vol. 11 (Art. VI), page 293.

	pH selected*
Bluegills (<i>Lepomis pallidus</i>), Wells ('15).....	7.7-7.9
Bullhead (<i>Ameiurus melas</i>), Wells ('15).....	7.4-7.7
Crappie (<i>Pomoxis annularis</i>), Wells ('15).....	7.3-7.4
Rock bass (<i>Ambloplites rupestris</i>), Shelford and Allee ('11).....	7.9
Golden shiner (<i>Abramis crysoleucas</i>), Shelford and Allee ('11).....	7.7

*pH calculated by Greenfield and Baker equation mentioned on p. 385.

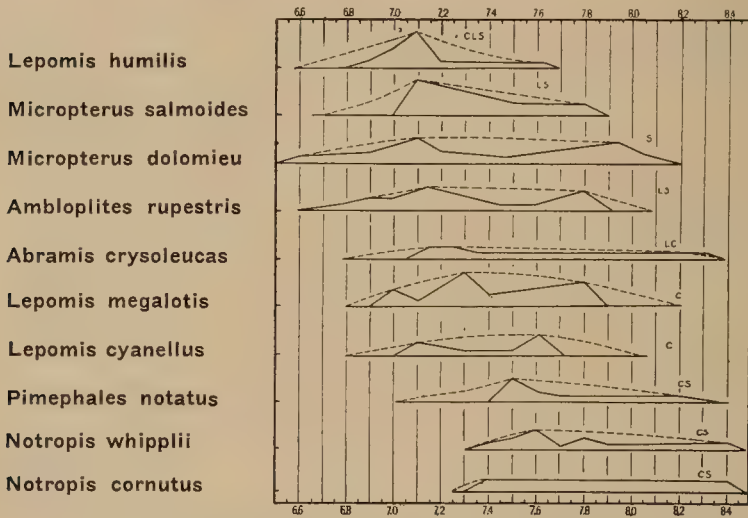


FIG. 1. Showing the range of hydrogen ion concentrations selected by ten species of fish (about 12 experiments per species). The actual selections are plotted, and a broken line indicates the author's impression as to the probable range in which they would be found. The polygons fall approximately in the order of occurrence in swift water. The letters indicate occurrence in creeks (C), small rivers (S), and in lakes and ponds (L). When two or three letters are used in connection with a polygon, the first one indicates the type of water in which the species is most numerous, and a single letter signifies that the species is commonly found only in that one type of water.

AN EXAMINATION OF CERTAIN ILLINOIS WATERS WITH SPECIAL REFERENCE TO HYDROGEN ION CONCENTRATION

A study of fish breeding-grounds was conducted by the author in 1919-20, and the pH values observed are shown in Table VI; the oxygen, in Table VII. There was a marked difference between the carp and bass breeding-grounds; in no case were they the same either at the top or bottom. The bass breeding-grounds were characterized by clean sand bottom; the carp grounds, by dark mud. Table VI shows sharp differences in oxygen content at the bottom at all dates on which they were examined.

TABLE VI

Showing oxygen in c.c. per liter and per cent. of saturation on fish breeding-grounds, 1919-20: Round Prairie, carp breeding-grounds; Warner's Cut, bass breeding-grounds; Hickory Creek, a typical unpolluted stream; ponds at the head of Lake Michigan.

Locality	July 16		Sept. 4		Nov. 28		Apr. 2		June 3		Mean	
	c. c.	%	c. c.	%	c. c.	%	c. c.	%	c. c.	%	c. c.	%
Round Prairie..	9.75	12	dry	dry	5.5	58	4.1	52	4.6*	71*	3.45	44
Warner's Cut...	8.0	150	dry	dry	9.2	95	5.4	70	(†)	....	7.5	105
Illinois River...	3.7	61	2.5	40	...	...	6.0	77	4.8	78	4.2	64
Pond I .....	....	...	14.7	235	7.8	94	....	....	6.9	110	9.8	146
Pond V .....	....	...	7.3	135	7.5	88	8.1*	183*	4.5	70	6.4	98
Pond VII, W...	....	...	17.8	330	8.1	96	....	....	7.5	120	11.1	182
Pond XIV .....	....	...	12.4	230	6.8	81	....	....	6.9	112	8.7	141

* Not included in the mean.

† High on-shore wind prevented our reaching this station. The strong waves should have given a 100% saturation.

TABLE VII

Showing the hydrogen ion concentration in different fish-waters, July, 1919, to June, 1920.

Locality	Bottom						Top					
	July 16	Sept. 4	Nov. 28	Apr. 2	June 3	Mean	July 16	Sept. 4	Nov. 28	Apr. 2	June 3	Mean
Lake Michigan..	....	....	...	...	....	....	7.9	7.9	7.9	7.8	7.9	7.9
Round Prairie...	7.15	dry	7.3	7.3	7.3	7.27	7.2	dry	7.3	7.4	7.6	7.4
Warner's Cut...	7.95	dry	7.9	7.4	...	7.75	8.2	dry	7.9	7.5	...	7.8
Ill. Riv., Jefferson St., Havana...	7.58	....	...	...	....	....	7.7	7.4	7.6	7.5	7.4	7.5
Spoon River	7.4	....	...	...	....	....	7.5	7.5	7.9	...	7.3	7.65
Hickory Cr.....	7.6	7.6	7.5	7.5	7.8	7.6	7.9	7.8	7.5	7.6	7.8	7.7
Pond I	7.55	7.4	7.9	...	8.0	7.7	7.6	7.8	7.9	....	7.9	7.8
Pond V	7.7	7.3	7.5	...	7.8	7.6	7.0	7.7	7.6	8.0*	7.9	7.5
Pond VII, W.....	8.5	7.85	7.9	...	7.4	7.9	8.2	8.2	7.9	....	7.9	8.05
Pond XIV	7.85	7.5	7.6	...	7.3	7.5	7.9	8.2	7.9	....	7.9	7.97
Pond VII, E.....	6.8	6.8	7.3	...	7.6?	7.1	7.2	....	7.3	....	7.7	7.4

* Not included in the mean.

The series of ponds was quite fully studied in 1909-1911 (see Biological Bulletin, volumes 21 and 22).

Pond I at that time contained bass, sunfish, and perch. Bare sand breeding-bottom.

Pond V contained perch and chub-suckers. Bare sand breeding-bottom.

Pond VII contained chub-suckers, golden shiner, bullhead, and mud minnow. No bare breeding-bottom. Pond VII, E, is much older than VII, W.

Pond XIV contained black bullheads. No bare breeding-bottom.

A few observations were made on pH at bottom under certain types of vegetation: Under white water-lilies, 6.9-7.2; under yellow water-lilies, 7.7-7.9; under duckweed and smartweed, 6.8-7.3.

GENERAL RELATIONS OF HYDROGEN ION CONCENTRATION TO OTHER FACTORS

1. *Relations of pH to dissolved oxygen.*—There are nearly always correlations between CO_2 content and dissolved oxygen, at least with a fairly constant 'alkalinity.' A fairly constant alkalinity exists in the sea. Relative to the sea, McClendon ('17a) states that "in so far as the sea is a closed system O_2 varies inversely with CO_2 , due to the action of organisms, the possible error being 30 percent." He presents a chart showing the amount of oxygen to be expected in sea water of various "alkalinities," etc. Below the thermocline a lake in summer is a closed system, and in so far as alkalinity remains constant there is an inverse relation of O_2 and CO_2 , which is, however, by no means constant. In some cases the sum of O_2 and CO_2 in c.c. per liter is a constant, but the relation is always an inverse one. This stability of the O_2 and CO_2 values probably depends upon circulation, diffusion, changes in alkalinity, etc., but in all the work described herein there is a direct relation between pH and O_2 (cf. Table VII and Table VI). When hydrogen ions content decreased, as indicated by higher pH figures, oxygen increased.

2. *Relations of pH to carbon dioxide and "alkalinity."*—In waters of about the same alkalinity the amount of free CO_2 is as good an index of its suitability for fishes as hydrogen ions (Shelford and Allee, '10). The amount of CO_2 means nothing, however, unless alkalinity be measured. The work of Greenfield and Baker ('20) shows that the H^+ ions may be calculated. The equation is

$$\text{H}^+ = \frac{4 \text{ CO}_2 \times 10^{-7}}{(\text{HCO}_3^-)} + 1 \times 10^{-8}$$

when CO_2 is expressed in p.p.m. and bicarbonate as p.p.m. CaCO_3 but when both bicarbonate and free CO_2 are expressed in c.c. per liter* the equation is

$$(\text{H}^+) = \frac{3.5 \times 10^{-7} \text{ CO}_2}{(\text{HCO}_3^-)} + 1 \times 10^{-8}$$

"To check the accuracy of these calculations, several samples of water, from a variety of sources and varying widely in mineral and organic content, were examined. Bicarbonate and free carbon dioxide

* Total must be used, i. e. bound and half-bound.

were determined according to 'Standard Methods of Water Analysis'. The free carbon dioxide titrations were continued to a faint pink which was persistent for 3 min. The hydrogen ion concentration was determined colorimetrically, using standard buffer solutions which had been checked by means of the hydrogen electrode. * * *

"In only one case [out of 63] was the difference between the determined and calculated P_{h^+} greater than 0.3, and the mean variation is about 0.1. It will also be noted that the wider variations occurred in the cases of low bicarbonate content, which is to be expected from the assumptions made in the development of the equation. * * *

"From their experience with the colorimetric P_{h^+} determinations, the authors do not feel that determinations can be made much more accurately than 0.2 P_{h^+} , using open tubes and ordinary methods of transferring the test sample to the tube. The effect of aeration of such unstable solutions as natural waters should amount to this much or more. It is advisable in all cases to make several determinations.

"The formula cannot be applied to waters which are alkaline to phenolphthalein. An attempt was made to develop such an equation, but no waters naturally alkaline to phenolphthalein were available for checking the calculations. For unusual cases of this kind and cases of low bicarbonate content, it may be better to use some more complete and more complex equation, such as has been developed by Prideaux (Proc. Roy. Soc. London (A) 91, 535)."

"Equations are developed for calculating H^+ -ion concentration, in which the carbon dioxide and bicarbonate are expressed in the manner in which they are ordinarily determined. These equations are less accurate with low bicarbonate concentrations, and do not apply to waters alkaline to phenolphthalein."

TABLE VIII

Comparison of calculated H ion concentrations with those determined colorimetrically. (Excerpts from a table by Greenfield and Baker.)*

Res. on evap.	Free CO ₂ p. p. m.	Bicarb. as p. p. m. CaCO ₃	P_{h^+} det.	P_{h^+} calc.	Error	Source of sample
375	0.0	154	7.9	8.00	— .10	Vermilion River
375	7.0	152	7.5	7.54	.04	Vermilion River
375	15.5	152	7.2	7.28	.08	Vermilion River
375	16.5	152	7.1	7.29	.19	Vermilion River
375	29.5	152	6.9	7.05	.15	Vermilion River
384	6.0	100	7.3	7.47	.17	Kankakee River
384	14.0	100	7.1	7.18	.08	Kankakee River
384	25.0	96	6.7	6.94	.24	Kankakee River
206	15.0	44	6.9	6.83	— .07	Ohio River
206	29.0	44	6.5	6.52	.02	Ohio River
206	30.0	44	6.5	6.52	.02	Ohio River
225	11.0	90	7.3	7.23	— .07	Miss. River

* Jour. Industr. and Eng. Chem., Vol. 12 (No. 10), p. 991. 1920.

TABLE IX

Values of pH corresponding to varying concentrations of free carbonic acid and bicarbonates calculated by the mass-law equation. (Table prepared by Greenfield and Baker.) Near-neutrality in bold-face figures. V. E. S.

HCO ₃ p.p.m. CaCO ₃	CO ₂ , parts per million												
	0	1	2	4	6	8	10	12	14	16	20	30	40
10	8.00	7.30	7.05	6.77	6.60	6.48	6.39	6.31	6.24	6.19	6.09	5.92	5.79
20	8.00	7.52	7.30	7.05	6.89	6.77	6.68	6.60	6.54	6.48	6.39	6.21	6.09
40	8.00	7.70	7.52	7.22	7.15	7.05	6.96	6.89	6.82	6.79	6.68	6.51	6.39
60	8.00	7.78	7.63	7.43	7.30	7.20	7.12	7.04	6.98	6.93	6.84	6.68	6.56
70	8.00	7.80	7.67	7.48	7.35	7.25	7.17	7.10	7.04	6.99	6.90	6.74	6.62
80	8.00	7.82	7.70	7.52	7.40	7.30	7.22	7.15	7.10	7.05	6.96	6.80	6.68
90	8.00	7.84	7.72	7.56	7.43	7.34	7.26	7.20	7.14	7.09	7.00	6.84	6.73
100	8.00	7.85	7.74	7.58	7.47	7.38	7.30	7.24	7.18	7.13	7.05	6.89	6.77
120	8.00	7.87	7.78	7.63	7.52	7.44	7.36	7.30	7.25	7.20	7.11	6.96	6.84
140	8.00	7.89	7.80	7.67	7.57	7.48	7.41	7.35	7.30	7.25	7.17	7.02	6.91
160	8.00	7.90	7.82	7.70	7.60	7.52	7.46	7.40	7.35	7.30	7.22	7.07	6.96
180	8.00	7.91	7.84	7.72	7.63	7.56	7.49	7.43	7.39	7.34	7.26	7.12	7.00

3. *Relations of pH to putrescibility and pollution.*—Under ordinary conditions putrescibility accompanies high free CO₂. This is determined partially, however, by alkalinity, but with a constant alkalinity, CO₂ usually varies directly with the putrescibility. In the Illinois River, with an alkalinity of 100 to 140 p.p.m. of CaCO₃, samples show pH values up to 7.2 with CO₂ at 8 p.p.m. several days after being shipped from points above Chillicothe. Here the calculated values were about 3 points too high, which was probably because the formula gives incorrect results in the presence of free ammonia. The low CO₂ values are surprising for the Illinois River.* Farther down the stream, at Chillicothe, September 6, 1919, I found pH 6.8 at the surface, and 6.9 at the bottom with green algae in evidence, and O₂ .9 c.c. per liter at the bottom, 20 feet from the west shore. On September 3, at Liverpool we found pH 6.9 at the bottom and O₂ .96 c.c. per liter, with the bottom fauna destroyed. The fact that CO₂ values appear to be small in this stream makes the calculated pH values too high. In this case, therefore, pH determinations would appear more significant than CO₂ determinations. Calculated values should not be used except where determinations are not practicable—e. g., in working over old data. Too many waters contain ammonia or other disturbing substances.

* Weston and Turner ('17) found high CO₂ in a polluted stream, but fail to give the alkalinity.

DISCUSSION AND SUMMARY OF RESULTS

Present-day methods of determining hydrogen ion concentration in detailed manner have been developed by biochemists, bacteriologists, and oceanographers; not by physical chemists, as one might expect. Its importance in the study of fishes came to the author's attention in course of experiments performed in 1911 (Shelford and Allee). This work was followed by that of several students. The important papers by Palitzsch and Sorensen—see bibliography in Clark ('20)—were overlooked by the writer until 1916. These important papers appear not to have been appreciated until 1915. The aid and advice of physical chemists was sought, but these investigators regarded differences in pH of less than unit value—e. g. between 8.0 and 9.01—of little importance, though they made important contributions to the subject. The turning-point of phenolphthalein was stated by Washburn ('15) to be pH 9.0; its turning-point in water analysis (faint pink lasting 3 minutes) is pH 8.0; all depends upon the method employed.

The summary of Wells' paper ('15) previously referred to, should read about as follows:

1. Hydrogen ion concentration is an important factor in determining the reaction and resistance of fishes.

2. Most fresh-water fishes select slightly alkaline water in a gradient, but when offered a gradient from the turning-point of phenolphthalein to higher hydroxyl ion concentrations (pH 8.0-9.0) the more alkaline end is selected.

3. The optimum CO_2 varies from 0 (pH 8.0) for bluegills to 6 c.c. per liter in water with about 200 parts per million alkalinity (pH 7.4-7.6) for sunfishes and crappies. Optimum sulphuric acid was not determined because of carbonates in the distilled water used.

4. The distribution of plankton in Wisconsin and New York lakes shows fewest animals in the stratum at the turning-point of phenolphthalein (pH 8.0), suggesting a negative reaction to water with pH 8.0.

5. No good results were obtained with once-distilled water because of carbonates present.

The chief occasion for criticism of Wells' paper is the confusion relative to neutrality. A repetition of his experiments, which was one of the purposes of the present paper, and a close study of his work shows that he regarded the turning-point of phenolphthalein (pH 8.0) as neutral, or "near enough" to it. The avoidance of pH 8.00 when this accompanied higher alkalinity, as found by Wells, has been confirmed by Miss Hall in case of young whitefish. The table constructed by Wells showing the avoidance of pH 8.0 by plankton (New York and Wisconsin lakes) is correct in this respect, but the columns to the right and left of the phenolphthalein neutrality are by no means comparable in hydrogen ion concentration. The statements by Wells relative to CO_2 , together with those in the paper of 1911 by Shelford and Allee, are correct only for the "alkalinities" used, which varied around 100 p.p.m. of CaCO_3 or 120 p. p. m. of HCO_3 . Several statements quoted from Wells ('15) and

Washburn ('15) in my chapter in Ward and Whipple's "Fresh Water Biology" are erroneous. Shull's "Principles of Animal Biology" (page 277) includes statements of a similar nature which should be corrected. These various statements relative to CO_2 optima, etc., are not to be regarded as errors when made; later evidence has merely shown that hydrogen ion concentration is a better index than CO_2 .

There are a number of general reasons for determining hydrogen ions, such as the close regulation of their concentration in the animal body and their apparent great physiological importance in vertebrates. The writer does not, however, wish to give the impression that he means to advocate the use of pH determinations to displace any other determinations now in common use unless it be CO_2 , and not even in this case until further investigations have been conducted.

CONCLUSIONS

Hydrogen ions should be determined for the following specific reasons:

1. The effect of various concentrations of oxygen are modified by the hydrogen ions present, particularly the ill effect of low oxygen on survival and development, which is increased by the high hydrogen ion concentration which accompanies it in waters of low alkalinity. In a general way the hydrogen ion concentration varies inversely with the oxygen content in bodies of water with stable alkalinity (e. g., see Tables VI and VII and Graph 1).

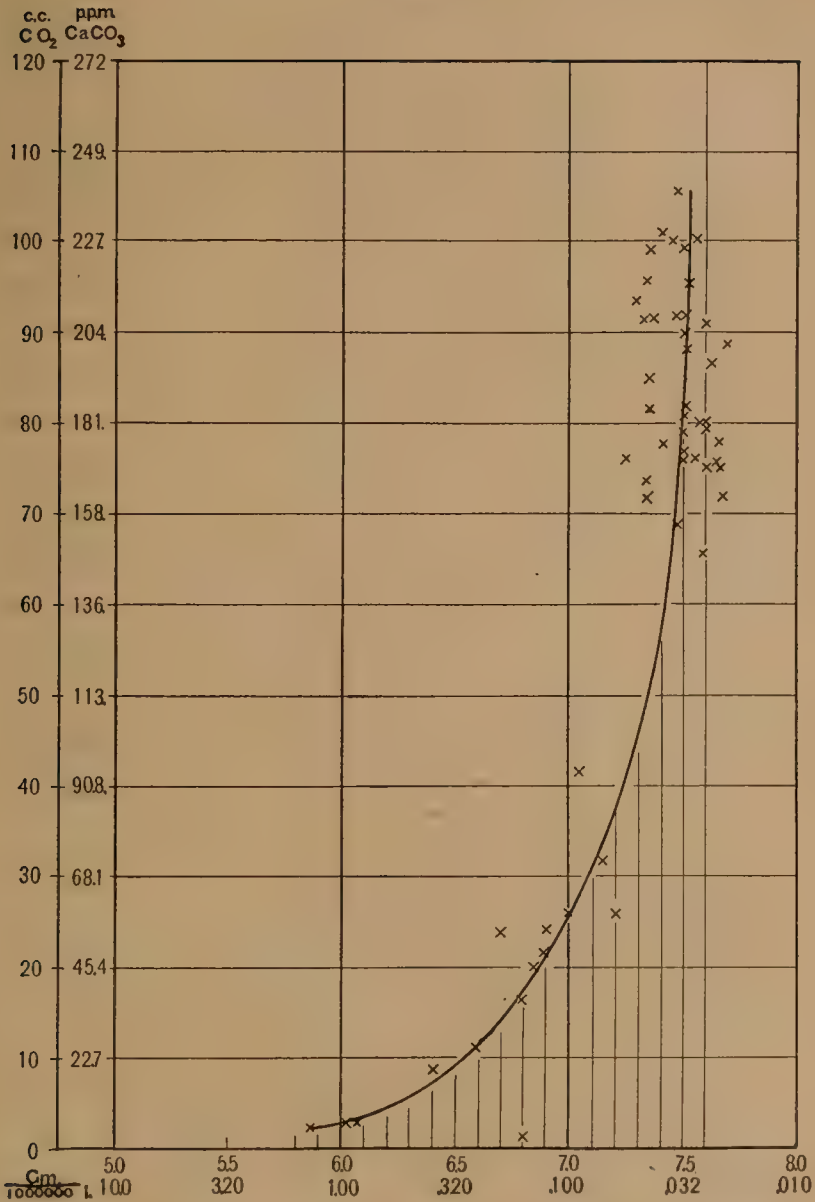
2. With the *same oxygen content*, different hydrogen ion concentrations have definite effects on the rate of development and time of survival of aquatic animals.

3. Many animals react definitely to hydrogen ion concentration (fishes, crayfishes, Entomostraca) in a manner similar to their reactions to temperature. Each species tolerates a rather wide range with a fairly definite optimum.

4. The determination of hydrogen ions is to be preferred to CO_2 determinations because it is the free hydrogen ions which are most effective, and, as shown in Table IX, column 6, for example, while the CO_2 remains constant (6 p.p.m.), hydrogen ions concentration changes by tenfold (pH 6.6 to 7.63) owing to difference in alkalinity.

5. Colorimetric determinations of pH are about as accurate as CO_2 determinations and can be made on the spot very quickly. With some simple device for collecting (see Richardson's Fig 6, page 372, Vol. XIII of this series), aeration can be reduced, and very small quantities of water used as contrasted with the usual 250 c.c. samples.

6. The distribution of plants and animals is correlated with hydrogen ion concentration.



GRAPH 1. Showing the range of hydrogen ion concentration accompanying a trace of oxygen in Wisconsin lakes. Calculated from data obtained by Birge and Juday ('11). At the left, alkalinity is shown as CO₂ and CaCO₃; below, hydrogen ions, as pH and as grams per million liters.

ACKNOWLEDGMENTS

The writer is especially indebted to Mr. R. E. Greenfield, of the Illinois State Water Survey, for numerous suggestions throughout the course of the investigation. The paper would have been deficient at several points but for his assistance. Acknowledgments are also due Messrs. R. E. Richardson and G. C. Baker for advice in various connections. I am also indebted to Mr. Ralph Bradford, Chief State Fish and Game Warden, for the black bass used; to the United States Fisheries Station at Fairport, Iowa, for bluegills furnished me; and to Dr. F. W. Mohlman, who kindly gave me the results of determinations of shipped Illinois River water.

BIBLIOGRAPHY

- Birge, E. A., and Juday, Chauncy
 '11. Inland lakes of Wisconsin. The dissolved gases of the water and their biological significance. Bul. XXII (Sci. Ser. 7), Wis. Geol. and Nat. Hist. Surv.
- Clark, W. M.
 '20. The determination of hydrogen ions. Baltimore. (Contains an extensive bibliography.)
- Forbes, S. A., and Richardson, R. E.
 '08. The fishes of Illinois. Vol. III, Nat. Hist. Surv. Ill. Sec. ed., 1920.
- Garrey, W. E.
 '16. Resistance of fresh-water fish to changes of osmotic and chemical conditions. Am. Jour. Physiol. 39: 313-329.
- Greenfield, R. E., and Baker, G. C.
 '20. Relationship of hydrogen ion concentration of natural waters to carbon dioxide content. Jour. Industr. and Eng. Chem. 12: 989-992.
- Hall, Ada R.
 '21. The effect of oxygen and carbon dioxide on the development of certain cold-blooded vertebrates. (To be published.)
- Jewell, M. E.
 '20. The quality of water in the Sangamon River. Bul. Ill. State Water Surv. 16: 230-246.
 '22. The fauna of an acid stream. Ecology, 3: 22-26.
- Juday, Chauncy
 '20. Behavior of the larvae of *Cörethra punctipennis* Say. Anatomical Record, 17: 340.

McClendon, J. F.

- '17. The use of the Van Slyke CO_2 apparatus for determination of total CO_2 in sea water. Jour. Biochem. 30: 259-263.
- '17a. The standardization of a new method for the determination of hydrogen ion concentration, CO_2 tension and CO_2 content of sea water. Ibid., 265-288.

Matthews, A. P.

- '15. Physiological chemistry. New York.

Powers, E. B.

- '21. The variation of the condition of sea water, especially hydrogen-ion concentration, and its relation to marine organisms. Puget Sound Biol. Station Pub. 2: 369-385.
- '21a. Experiments and observations on the behavior of marine fishes toward hydrogen-ion concentration of sea water in relation to their migratory movements and habitat. Ibid., 3: 1-22.
- '22. The physiology of the respiration of fishes in relation to the hydrogen ion concentration of the medium. Jour. Gen. Phys., 3: 305-317.

Richardson, R. E.

- '21. The small bottom and shore fauna of the middle and lower Illinois River and its connecting lakes, Chillicothe to Grafton; its valuation; its sources of food supply; and its relation to the fishery. Bul. Ill. Nat. Hist. Surv., 13: 372, Fig. 6.

Stickney, F.

- '22. The relations of nymphs of *Libellula pulchella* to acid and temperature. Ecology, 3: 250-254.

Washburn, E. W.

- '15. Introduction to the principles of physical chemistry. New York.

Wells, M. M.

- '15. Reaction and resistance of fishes in their natural environment to acidity, alkalinity, and neutrality. Biol. Bul. 29: 221-257.

Weston, R. S., and Turner, C. E.

- '17. Studies on the digestion of a sewage-filter effluent by a small and otherwise unpolluted stream (Coweaset Cr.). Contr. San. Res. Lab. and Sewage Exper. Station, 10: 1-96.

Wherry, E. T.

- '21. Soil acidity and a field method of measuring it. Ecology, 1: 160-173.



STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION
DIVISION OF THE
NATURAL HISTORY SURVEY
STEPHEN A. FORBES, Chief

Vol. XIV.

BULLETIN

Article X.

On the Numbers and Local Distribution
of Illinois Land Birds of the Open
Country in Winter, Spring,
and Fall

BY
STEPHEN A. FORBES
and
ALFRED O. GROSS



PRINTED BY AUTHORITY OF THE STATE OF ILLINOIS

URBANA, ILLINOIS

October, 1923

STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION
A. M. SHELTON, *Director*

BOARD OF
NATURAL RESOURCES AND CONSERVATION

A. M. SHELTON, *Chairman*

WILLIAM TRELEASE, *Biology*

JOHN M. COULTER, *Forestry*

EDSON S. BASTIN, *Geology*

WILLIAM A. NOYES, *Chemistry*

JOHN W. ALVORD, *Engineering*

KENDRIC C. BABCOCK, *Representing the*
President of the University of Illi-
nois

THE NATURAL HISTORY SURVEY DIVISION

STEPHEN A. FORBES, *Chief*



SCHNEPP & BARNES, PRINTERS
SPRINGFIELD, ILL.

1922

876—1200

ARTICLE X.—*On the Numbers and Local Distribution of Illinois Land Birds of the Open Country in Winter, Spring, and Fall.* BY STEPHEN A. FORBES AND ALFRED O. GROSS.

Probably nothing can seem further removed from the sources of interest in ornithology which attract the general bird lover to an observation and study of birds than a mass of statistical data concerning the numbers of the different species in different seasons, regions, and habitats; but with a sufficient exercise of the imagination one may translate this dull array of figures into a captivating vision of the actual bird life of the broad areas from which the data have been drawn—a vision which should add immensely to our conception of the significance of birds in the life of the world and of their interest to the observer and the student of nature. We commonly think of a robin as one of a small, scattered group on a little part of a lawn, searching, with captivating grace and individuality of attitude and action, for the earthworms and insects of its breakfast menu; or of a single meadowlark as piping its lovely lay with generous abandon in the dewy morning from a fence post beside the meadow; but we may multiply our pleasure in the recollection a thousand fold if we can think at once of hundreds of thousands of each, spread over a vast area, their numbers thickening here, diluted there, according to situation and circumstance, like a delicately shaded pigment used to paint a robin picture or a meadowlark picture of the State of Illinois. The reader of our papers must supply the colors, it is true, but that will be easy if he is a well-equipped colorist. It is ours to show where and how and in what depth of tint they must be laid on to make the picture as true as possible to the life of field and forest, thicket and swamp, summer and winter, north and south.

It has been our general plan to work at first with broad strokes of the full brush, refining upon our neutral background by degrees and ending, as we hope to do in a paper following the present one, with the final details for each species taken up separately and followed all over the state and around the year. This one time more, however, we must resume our method of blocking in the skeletal outlines and the basal features of the local ornithology, as intelligently as we can with somewhat inadequate materials, leaving it to others to give life and finish to the sketch.

THE WINTER BIRDS

In planning the presentation of the products of a partial survey of the land birds of Illinois made in 1906, 1907, 1908, and 1909, it seemed best that we should first discuss the species resident in the state in summer and in winter, respectively, following with the much more difficult

treatment of the birds of the transition periods covering the spring and fall migrations. Our report on the summer residents has already been published*, and we have next to report on the winter residents of the state, so far as they were observed in a single season's travel.

The winter season is, of course, in strong contrast to summer in respect to the dominant species of birds and their numbers, and in the greater freedom of their movements, since they have only their own pleasures and welfare to seek, quite free from responsibility for a following generation which in summer individualizes their interests, chains them to one locality, and dominates most of their activities. In winter their gregarious tendencies can assert themselves unchecked, and they move much more generally in flocks, sweeping widely from place to place, as the weather changes, in a free search for shelter and a comparatively scanty food supply. The extremes of the state are also much more unlike at this time than in summer, the southern Illinois birds living under conditions approaching those of the perpetual summer of the tropics, while the northern Illinois birds pass their winter not far outside the edge of a frigid zone. How these differences are expressed in the number of species as well as the population densities of northern and southern Illinois respectively, will presently be shown.

The winter dates of our Illinois bird survey extend from November 23, 1906, to February 21, 1907, the northern Illinois observations having been made from November 23 to 30 and January 2 to 16, those for central Illinois from December 3 to 18 and January 16 to February 1, and those for southern Illinois from February 6 to 21. They show settled winter conditions in each section of the state except that three fall migrants, the Canada goose, Wilson's snipe, and pipit, were seen in northern Illinois in November in very small numbers—2, 1, and 8 respectively. The distances traveled on these winter trips, the acreage covered by the survey, the numbers of birds identified and counted, and the average numbers per square mile are shown in the following table.

ACREAGE OF SURVEY AND NUMBER OF BIRDS
WINTER OF 1906 AND 1907

Section	Miles traveled	Acreage covered	Ratio	No. of birds	Numbers per square mile
Southern	88.9	1422.40	1	1858	836
Central	147.6	2638.76	1.86	1815	440
Northern	130.1	2317.21	1.63	1520	420
State	366.6	6378.37		5193	520

* The Numbers and Local Distribution in Summer of Illinois Land Birds of the Open Country. By Stephen A. Forbes and Alfred O. Gross. Bul. Ill. State Nat. Hist. Surv., Vol. XIV, Art. 6, p. 187-218, Pl. 35-70.

Comparing winter and summer birds of our record for the three sections of the state in the year 1906-07, we find that the winter birds per square mile were fewer by 32% than those of the summer time for central and northern Illinois (430 and 630 respectively), but that the southern Illinois birds were 22.6% more numerous per square mile in winter than in summer (836 to 682). This southward concentration of the birds of the winter will, of course, vary greatly according to the character of the season, severe fall and winter weather equalizing the Illinois distribution by driving the more sensitive species quite beyond the boundaries of the state.

WINTER AND SUMMER BIRDS PER
SQUARE MILE, 1906-07

	<i>Winter</i>	<i>Summer</i>
Southern	836	682
Central	440	650
Northern	420	610
State	520	644

The complete list of the winter birds of our survey numbers fifty-two species, forty-two of which were in southern, twenty-nine in central, and thirty-one in northern Illinois, or thirty-seven in both the latter taken together. Northern and central Illinois were closely alike in the species of their winter birds, differing mainly in the fact that the horned lark and redpoll came down in very small numbers into the northern part of the state without reaching central Illinois, that another northerner, the Lapland longspur, was very abundant in northern Illinois but rare in central, and that the cardinal, most abundant in the south in winter, was seen in central Illinois but not in northern. In southern Illinois, on the other hand, sixteen species were found which were not seen farther north. Some of these doubtless occurred in central and northern Illinois, but the fact that they were not seen there in 278 miles of travel but were found in southern Illinois in less than a third of that distance, is an indication that, if not wanting in the north, they were at any rate much more abundant southward. Furthermore, the numbers of winter birds per square mile were virtually equal in the two northernmost sections, 100 birds in northern Illinois corresponding to 105 in central, but in southern Illinois the number was virtually twice as great as that of the other sections united, 100 of the latter corresponding to 199 of the former. The following thirteen of our fifty-two winter species are required to make up 85 per cent. of the total number of birds seen and counted in the state, and these taken together averaged 115 to the square mile, or about two birds to every three acres, leaving seventy-five birds to the square mile for the remaining thirty-nine species, or more than eight acres to the bird.

NUMBERS OF THE MORE ABUNDANT WINTER BIRDS OF ILLINOIS, 1906 AND 1907 (85 PER CENT. LIST)

Names	Nos. seen and counted	Nos. per sq. mile
Crow	768	77
Lapland longspur	677	68
Junco	567	57
Prairie horned lark	476	48
English sparrow	414	42
Goldfinch	336	34
Tree sparrow	303	30
Meadowlark	269	27
Quail	234	24
Blue jay	114	11
Cardinal	93	9
Mourning dove	88	9
Chickadee	87	9
Totals	4426	445

THE DATA BY SECTIONS OF THE STATE

Turning now to the sections of the state, we find 1858 birds recorded from southern Illinois—an average of 836 to the square mile. Fourteen of the forty-one species are needed to make up 85 per cent. of the whole number. These more abundant species totaled 706 to the square mile, and the twenty-seven less abundant species, 130 to the mile. Otherwise stated, the fourteen prominent species averaged 112 birds each and the twenty-seven less abundant species averaged fourteen each. The numerical data for the more abundant birds are as follows:

NUMBERS OF THE MORE ABUNDANT WINTER BIRDS OF
SOUTHERN ILLINOIS, 1906 AND 1907
(84.5 PER CENT. LIST)

Species	Numbers seen and counted	Numbers per square mile
Junco	416	187
Meadowlark	268	121
Quail	180	81
Bluebird	82	37
Mourning dove	81	36
Blue jay	79	36
Turkey vulture	70	31
Prairie horned lark	63	29
Tufted titmouse	62	28
Carolina chickadee	60	27
Purple finch	58	26
Tree sparrow	53	24
Cardinal	51	23
Song sparrow	44	20
Totals	1567	706

Sixty-nine per cent. of the birds belong to 34 permanent resident species, and 31% to 7 species of winter residents, the latter mainly juncos, purple finches, tree sparrows, and white-throated sparrows.

Central and northern Illinois resembled each other and differed from southern Illinois in the fact that although they are widely unlike in the statistical particulars of our survey, the winter fields of both were swept by ranging flocks of virtually the same gregarious species, which made by far the greater part of the bird population of both sections. Six species out of thirty recorded composed, in these northern sections, 87 and 88 per cent. of the whole number seen. The two following lists of species of principal winter birds differ only in the substitution of the junco in central Illinois for the Lapland longspur in northern; and their combination into one improves our picture of the winter bird life of these parts of the state.

NUMBERS OF THE PRINCIPAL WINTER BIRDS OF CENTRAL ILLINOIS, 1906 AND 1907, (88.5 PER CENT. LIST)

Species	Numbers seen	Numbers per square mile
Crow	526	128
Prairie horned lark	338	82
English sparrow	332	81
Goldfinch	153	37
Junco	141	34
Tree sparrow	113	27
Total	1603	389

NUMBERS OF THE PRINCIPAL WINTER BIRDS OF NORTHERN ILLINOIS, 1906 AND 1907, (87 PER CENT. LIST)

Species	Numbers seen	Numbers per square mile
Lapland longspur	675	186
Crow	207	57
Goldfinch	179	49
Tree sparrow	137	38
Prairie horned lark	75	21
English sparrow	50	14
Total	1323	365

COMBINED MOST ABUNDANT LIST, 1906 AND 1907, CENTRAL
AND NORTHERN ILLINOIS, (83.3 PER CENT. LIST)

Species	Numbers counted	Per square mile
Crow	733	95
Lapland longspur	675	87
Prairie horned lark	413	53
English sparrow	382	49
Goldfinch	332	43
Tree sparrow	250	32
Junco	141	19
Total	2926	378

Comparing the foregoing ratios with those of southern Illinois, we see in the winter birds of the southern section a difference from the northern sections in the number of the more dominant species like that to which attention was called in our discussion of the summer birds of the state. To make 85 per cent. of the total number of winter birds we must take for southern Illinois more than 36 per cent. of the species, and for central and northern Illinois only 19 per cent.—fifteen species in southern Illinois as compared with seven in northern-central. The relatively greater ecological complexity of the southern part of the state is thus reflected, in winter as well as in summer, in the greater number of species of birds with numbers large enough to make them important as members of the ornithological community.

The winter birds of central and northern Illinois taken as one area, were fewer per square mile by 32 per cent. than those of the summer-time (430 to 630), but the southern Illinois birds were 22.6 per cent. more numerous per square mile in winter than in summer (836 to 682). Our general averages per square mile for the state as a whole were 520 for the winter and 644 for the summer—the winter number nearly 21 per cent. smaller than the summer.

RESIDENCE CLASSES AND THEIR SEASONAL MOVEMENTS

From this point onward, we shall make much use of tables showing the residence classification of the species dealt with, and a few words of general information seem necessary.

Although the birds of a locality or of an area of moderate size and fairly uniform ecological condition, are somewhat definitely divisible into the four classes of permanent residents, winter residents, summer residents, and migrants (the last term being used for those which pass entirely through the area in migration), a strict classification on this basis is impracticable since the northward and southward range of a species

may vary considerably in different years if the critical seasons are much unlike, and the numbers of a species diminish so gradually as the boundaries of its range are approached, that it is usually impossible to draw them distinctly. We have made as definite a residence classification of the birds of our lists for each section of the state as our data will permit, using not only our own observations but all available information both published and unpublished, ignoring, however, merely occasional occurrences and scanty numbers, since these are ecologically insignificant; and we have drawn upon our statistical data to determine as accurately as possible the movements and numerical relations of the different classes in the four annual seasons and the three sections of the state.

It is an interesting fact that only 17.1 per cent. of the 41 midwinter species of our list were winter residents in southern Illinois, the remaining 82.9 per cent. being permanent residents in that region. In central Illinois, on the other hand, permanent resident species were 64.3%, and in northern Illinois 57.2% of the whole number, the ratios thus diminishing rapidly northward. While the winter residence ratios remained fairly uniform (17.1, 17.9, and 19.0, south to north), the summer species present in winter increased in numbers northward (0.0, 14.3, and 19.0), and the migrant species were either absent, or present in only insignificant number.

COMPARISON OF RESIDENCE RATIOS IN SECTIONS OF THE STATE, WINTER OF 1907

<i>Species</i>	Permanent	Winter	Summer	Migrant
Northern	57.2	19.0	19.0	4.8
Central	64.3	17.9	14.3	3.5
Southern	82.9	17.1	0.0	0.0
<i>All Birds</i>				
Northern	62.9	35.5	1.3	0.3
Central	84.3	15.0	0.6	0.1
Southern	69.4	30.6	0.0	0.0
<i>Natives</i>				
Northern	61.4	37.0	1.3	0.3
Central	80.8	18.4	0.7	0.1
Southern	68.9	31.1	0.0	0.0

This is all, of course, what we should expect, more species of birds remaining throughout the year in the more equable southern climate, and the number driven southward in winter increasing as we pass to areas of greater cold. The agreement of our statistics with this obvious inference tends to give us confidence in their sufficiency, although the validity of the exact numbers of our tables is nevertheless left in doubt.

It may seem strange at first that species properly classed as summer residents throughout the state should be more largely represented in

winter in northern Illinois than in central, and more so in central than in southern, but evidently the larger the number of summer species retiring southward in winter the larger will be the number that will leave a few representatives in especially favorable haunts. The summer residents which seemingly linger into winter are very likely migrants from the northern edge of the summer area of the species, accustomed to a lower temperature throughout the year than their fellows. It seems possible, if not probable, that the whole mass of a species moves in migration, not as a mob, but as a more or less fixed array, those northernmost at the beginning of the movement being also northernmost at its end, each part of the array seeking the kind of climate to which it has become accustomed. If this is the case, the summer birds of northern Illinois whose area of summer residence extends farthest northward will be most likely to leave a recognizable number of representatives in northern Illinois in winter, and this will be especially likely if the species contains a large number of birds. Other things being equal, members of the migrating species represented by the largest numbers will be most likely to be found in winter farthest north.

Our tables of residence classification for the three sections of the state and the four seasons of the year show the effect of change of season on the geographical distribution of the *species* tabulated, and the first division of each table is thus the essential part of it; in this the *species* is the unit and not the *bird*. The *number of birds* belonging to a species is a secondary matter in determining its geographical distribution, and as the second and third sections of our tables deal with such numbers, they have relatively little significance in a residence classification.

WINTER BIRDS IN HABITATS

The acreages of some of the vegetation areas covered by the winter operations of our bird survey—namely, swamps, 22 acres, orchards, 38 acres, yards and gardens, 26 acres—are so small as to be of doubtful value for our purposes, but those of cereal and forage crops, woods, shrubbery, and waste and fallow lands, ranging from 250 to 1790 acres each, may be used to fair advantage. There is, of course, much less to differentiate them as bird resorts when vegetation is dead over all of them and the ground is often covered with snow than there is in the varied and fruitful summer season. The gregarious habit of most winter birds calls for a larger number of observations as essential to dependable averages; the character of the season has much to do with the abundance and southward range of several of our typical winter residents; and it is only by rare chance that the data of a single winter can approximate an average for the winters of a decade. Nevertheless our recorded numbers from different habitats seem worthy of report as a means of depicting the contrast in the bird population of the state

in the seasonal extremes of the year, a view of which is necessary to an understanding of the transition periods of spring and fall.

ACREAGES OF WINTER BIRD SURVEY OF 1906 AND 1907

Habitats	Southern Illinois	Central Illinois	Northern Illinois	State
Corn	229.75	876.12	683.93	1789.80
Wheat	289.29	259.42	76.83	625.54
Stubble	161.99	342.25	305.62	809.86
Plowed ground	18.30	325.31	223.41	567.02
Pasture	184.34	501.58	498.43	1184.35
Meadow	114.34	198.48	305.00	617.82
Swamp	22.27	.....	.....	22.27
Woods	209.55	48.99	58.64	317.18
Orchard	19.02	16.36	2.44	37.82
Shrubs	33.09	11.66	17.95	62.70
Waste and fallow	116.41	35.40	97.86	249.67
Yards and Gardens	8.18	5.47	12.30	25.95
Miscellaneous	15.87	17.72	34.80	68.39
Total	1422.40	2638.76	2317.21	6378.37

In the search for food and protection, the winter birds of the state (mainly seed eaters) were found in the largest numbers in corn fields, pastures, and woodlands—about a fourth of all in the first, a sixth in the second, and an eighth in the last of these situations. In numbers per square mile, the ratios were of course very different, corn fields, wheat, stubble, and pastures having about equal averages, meadows and fields of plowed ground considerably smaller, and the tree and shrub association (orchards, woods, and shrubbery), nearly five times as many to the unit of area as the open country. Indeed, from our numbers per square mile for the whole state it would seem that there are in winter but three classes of bird habitat, the open fields, the woods, wastes, and orchards, and yards, gardens, and shrubbery, represented in our survey by the very unequal areas of 5596, 605, and 89 acres, respectively; the first with 423 birds to the square mile, the second with 1153, and the third with 2676.

To what extent the higher densities are related inversely to the smaller areas of the classes of habitats in which they occur, the birds characteristic of the less extensive habitats being found merely to concentrate there, it is impossible for us to say. The same general relations as to density ratios hold in the sections of the state taken separately, although differences of winter climate and the occasional occurrence of flocks of juncos, tree sparrows, and Lapland longspurs so outweigh the averages in many cases that the detailed figures have little significance.

This disturbing effect of the gregarious habit of winter birds is illustrated by the enormous number per square mile found in the 5½

acres of yards and gardens surveyed in central Illinois—an overplus wholly due to English sparrows—and by the large northern Illinois averages in wheat and meadows, due to flocks of Lapland longspurs encountered in these fields.

NUMBERS SEEN AND COUNTED OF ALL WINTER BIRDS IN THE SEVERAL HABITATS

Habitats	Southern Illinois	Central Illinois	Northern Illinois	State
Corn	497	660	225	1382
Wheat	59	28	326†	413
Stubble	134	135	258†	527
Plowed ground	3	160	30	193
Pasture	164	390	272	826
Meadow	99	23	193†	315
Swamp	42	....	....	42
Woods	521	52	41	614
Orchards	65	14	1	80
Shrubs	104	80	25	209
Waste and fallow	158	110	127	395
Yards and Gardens	10	150*	2	162
Miscellaneous	2	13	20	35
Total	1858	1815	1520	5193

* All English sparrows.

† Mainly Lapland longspurs.

NUMBERS PER SQUARE MILE OF ALL WINTER BIRDS IN THE SEVERAL HABITATS

Habitats	Southern Illinois	Central Illinois	Northern Illinois	State
Corn	1384	482	211	494
Wheat	131	69	271	423
Stubble	529	252	540	417
Plowed ground	105	315	86	218
Pasture	569	498	349	446
Meadow	554	74	405	319
Swamp	1207	....	....	....
Orchard	2187	548	....	1354
Woods	1591	679	447	1239
Shrubs	2011	4391	891	2133
Waste and fallow	555	1989*	831	1013
Yards and Gardens	782	17550†	1041	3995
Miscellaneous	81	469	368	328

* Mainly tree sparrows.

† English sparrows only.

WINTER BIRDS PER SQUARE MILE IN GROUPS OF HABITATS

	Southern	Central	Northern	State
Open fields	626	357	402	423
Woods, waste and orchards	1380	1112	680	1153
Shrubbery, yards and gardens	1768	8593	7849	2676

The *corn field* in winter evidently presents a less dreary aspect to birds than to man, as is shown by our state average of nearly 500 birds to the square mile in that situation. To a winter bird what we call a corn field may often seem to be rather a field of weeds, mainly seed-bearing grasses of the kinds which are likely to take possession, especially in a wet season, after the corn is "laid by." Comparing the corn-field ratios of birds with the winter averages for all habitats we find them only half as large in northern Illinois (211 in corn to 420 for the whole area), a little larger in central Illinois (482 to 440) and 65 per cent. larger in southern Illinois (1384 to 836). The high ratio in *southern Illinois* corn fields was mainly due to flocks of juncos, ranging in number of birds from 3 to 24, only 4 of the 133 corn-field juncos recorded having been single birds; to equally large flocks of meadow-larks in corn fields (3 to 36 in numbers, only 2 of 134 of these birds having been seen singly), and to one flock of 74 mourning doves. Next to these dominant species came quails in two covies of 18 and 27 each, crows, solitary or only 2 to 5 together, red-headed woodpeckers, single of course, and tree sparrows in one flock of 8 but otherwise scattered.

In *central Illinois* the crow was the dominant species in our corn field records, mainly however, by reason of two large flocks, one of 44 and another with an estimated number of 400.* The next in order of prominence was the English sparrow, but with a number per square mile only half the general winter average of the species for the state (41 to 81). An interesting minor item is the occurrence of twenty cardinals in corn, a much larger number than in any other central Illinois situation, and nearly twice as large as was found in the corn fields of southern Illinois.

In the *northern* part of the state the leading species were the Lapland longspur, mainly 2 to 4 in a place but with one flock of 38, and a flock of 55 goldfinches.

* These were seen December 18 in fields which were probably not yet husked, and the crows were very likely helping themselves to corn kernels from the tips of the ears. To the larger grain-eating birds, husked and unhusked corn fields are of course very different habitats, but unfortunately our field notes contain no records of this distinction.

NUMBERS PER SQUARE MILE OF THE PRINCIPAL WINTER BIRDS IN CORN

Species	Southern	Central	Northern	State
Quail	75	13	0	16
Prairie chicken	0	0	18	7
Mourning dove	220	*	6	31
Flicker	50	0	0	6
Crow	39	341	28	183
Meadowlark	373	0	0	48
English sparrow	0	41	12	25
Goldfinch	8	0	54	22
Lapland longspur	0	0	61	23
Tree sparrow	33	24	17	23
Junco	370	29	0	61
Total	1168	448	196	445

* Present, but in trivial number.

Our sectional data for *wheat* are greatly distorted by flocks of Lapland longspurs in northern Illinois, bringing the general average in wheat fields there to twice that for the southern and four times that for the central section. These birds were in three flocks of 9, 13, and 175, respectively. The prairie horned lark was the only other species especially abundant in northern Illinois wheat fields, where it averaged 317 to the square mile, a ratio mainly due, however, to a single flock. The wheat fields of central Illinois were nearly destitute of birds, the leading species there being juncos, found but three times, in numbers from 1 to 9, and the tree sparrows, found but once, in a flock of 5. In southern Illinois, on nearly half a section of wheat, only 59 birds were to be found, juncos in the largest number (31 to the square mile) and next these the prairie horned larks, meadowlarks, and bluebirds, each in about two-thirds the above average.

In the table next following, gross irregularities of the sectional lists are smoothed down somewhat in the column of averages for the state as a whole, but they are still too large to have much if any value as statistics. They show what was actually found by a limited number of observations in one winter, but warrant no inference that they would be duplicated in any similar area in another.

NUMBERS PER SQUARE MILE OF THE PRINCIPAL WINTER BIRDS IN WHEAT

Species	Southern	Central	Northern	State
Prairie horned lark	24	5	317	52
Crow	0	7	33	7
Meadowlark	24	*	0	11
Lapland longspur	0	0	2366	291
Tree sparrow	0	12	0	5
Slate-colored junco	31	32	0	28
Cardinal	0	5	0	2
Bluebird	22	0	0	10
Total	101	61	2716	406

The record for fields of *stubble* is quite as irregular as that for wheat, quails and meadowlarks dominating in southern Illinois, prairie horned larks in central, crows and Lapland longspurs in northern, and the last of these in the state as a whole, with prairie horned larks and crows next in order. An interesting item is the occurrence in southern Illinois of sufficient numbers of song sparrows and bluebirds to bring these species into the "more abundant" list.

NUMBERS PER SQUARE MILE OF THE PRINCIPAL WINTER BIRDS IN STUBBLE

Species	Southern Illinois	Central Illinois	Northern Illinois	State
Quail	142	19	8	40
Prairie horned lark	79	131	31	83
Crow	8	52	119	69
Meadowlark	158	*	0	33
English sparrow	0	34	*	15
Lapland longspur	0	0	335	127
Tree sparrow	36	6	13	14
Song sparrow	24	0	0	5
Bluebird	24	0	0	5
Total	471	242	506	391

* Present in only trivial numbers.

On *plowed ground*, the most striking feature was the dominance of the prairie horned lark in central Illinois—211 to the square mile on the 325 acres of that habitat. Over four-fifths of these birds were in two flocks of 37 and 48 respectively, the remainder occurring in scattered small numbers. The other important averages were 55 juncos and 33 English sparrows to the square mile in central Illinois. Only three birds were found on eighteen acres of southern Illinois plowed land, while on 223 acres in northern Illinois there were approximately equal numbers of prairie horned larks and Lapland longspurs, with about half as many English sparrows. The leading species for the state as a whole (really only central and northern Illinois, since the southern acreage of plowed ground was very small), were the prairie horned lark with 130 to the square mile, junco with 32, and English sparrow with 24.

NUMBERS PER SQUARE MILE OF THE PRINCIPAL WINTER BIRDS ON PLOWED GROUND

Species	Southern Illinois	Central Illinois	Northern Illinois	State
Prairie horned lark	0	211	23	130
Crow	0	0	*	*
English sparrow	0	33	11	24
Lapland longspur	0	*	20	10
State-colored junco	0	55	0	32
Undetermined	0	0	20	8
Total	0	299	74	204

* Trivial numbers only.

The winter data of our *pasture* area of nearly 500 acres are especially interesting and much more satisfactory than those just discussed, the only important irregularity being excessive numbers of prairie horned larks (186 to the square mile in central Illinois as compared with northern and southern, which are 14 and 80 respectively). It is true that the tree sparrows were more abundant to the northward and juncos to the southward, but this is consistent with the winter distribution of the species—the juncos going as far to the south as the Gulf States and the tree sparrows tending to linger in the latitude of Kentucky and the Carolinas. Otherwise the numbers of the more abundant species are fairly similar in central and northern Illinois, only the chickadee being notably commoner in the northern section. That quails, flickers, meadowlarks, purple finches, cardinals, and bluebirds should be much the most numerous in southern Illinois pastures was to be expected for various reasons—the greater abundance of birds in general to the southward, the usual avoidance of rigorous winter weather by meadowlarks, cardinals, and bluebirds, the much larger area in forests in southern Illinois, and the more abundant ground-cover of kinds sought by the quail.

For the state as a whole, we found birds of the winter pasture prominent in about the following order: goldfinch, prairie horned lark, English sparrow, junco, crow, tree sparrow, purple finch, chickadee, meadowlark, quail, and bluebird, in averages ranging from 133 to the square mile for the first to 8 for the last of this series.

NUMBERS PER SQUARE MILE OF THE PRINCIPAL WINTER BIRDS IN PASTURES

Species	Southern Illinois	Central Illinois	Northern Illinois	State
Quail	56	0	0	9
Turkey vulture	21	0	0	3
Flicker	21	7	0	6
Prairie horned lark	80	186	14	97
Crow	14	22	36	27
Meadowlark	59	0	0	9
Purple finch	108	0	0	16
English sparrow	0	45	40	36
Goldfinch	0	167	149	133
Tree sparrow	7	5	55	27
Slate-colored junco	87	41	0	31
Cardinal	14	10	0	7
Chickadee	0	6	21	11
Bluebird	45	0	*	8
Total	512	489	315	420

* Only trivial numbers.

Meadows differ from pastures in our winter record in the smaller number of birds per square mile (319 as compared with 416); in the smaller number also of the more abundant species (6 and 10 respectively)

necessary to make up the 85 per cent. list; and in the much greater irregularity of numbers per square mile in the different sections and habitats. Meadows seem, in short, from our data to be a much less attractive situation for birds than pastures in winter as well as in summer, most of those found there being wandering flocks of gregarious species. The contrast was especially strong in southern Illinois, where the more abundant list contained three species in meadows and eleven in pastures. The inadequacy of our data for meadows is especially shown, however, by the numbers in central Illinois, where, with a meadow acreage two-thirds that of northern Illinois, the number of birds per square mile was less than a fifth as large, a fact of which we can offer no plausible explanation except that the data of our record are too few to give us fair averages where the birds are so largely gregarious.*

NUMBERS PER SQUARE MILE OF THE PRINCIPAL WINTER BIRDS IN MEADOWS

Species	Southern Illinois	Central Illinois	Northern Illinois	State
Quail	122	0	0	19*
Prairie horned lark	14	23	6	13*
Blue jay	0	10	0	3
Crow	0	6	40	23*
Meadowlark	340	0	0	54*
Lapland longspur	0	0	332	169*
Tree sparrow	0	10	6	6*
Slate-colored junco	0	10	0	3
Total	476	59	384	290

* The figures starred make up 85 per cent of the total number of winter birds in Illinois meadows.

The southern Illinois area of $22\frac{1}{4}$ acres of *swamp* brought under observation yielded 42 birds of eleven species, of which three, however, were hawks and one a turkey vulture. The others, excepting a single bluebird, were all distinctively woodland species. The acreage is so small that the frequency figures have but little value.

Our *woodland* area of 317 acres, two-thirds of which is in southern Illinois, was well stocked with birds for the winter season—1591 of them to the square mile in southern, 679 in central, and 117 in northern Illinois. The general state average per square mile was 1239, representing thirty-one species, twenty-nine of which are in the southern Illinois list, eleven in the central, and ten in the northern. The commonest species was the junco, the next the blue jay, the next the turkey vulture, and then the tufted titmouse, all prominent on the state list because of their dominance in southern Illinois. Seven of the 87 per cent. woodland list were, in fact, seen in southern Illinois only, namely, the quail, turkey

* For a discussion of gregarious and solitary species, see Article 6, Volume XIV, already cited.

vulture, purple finch, junco, song sparrow, Carolina chickadee, and bluebird. The tufted titmouse, occurring there at an average of 131 to the square mile, was noticed in woodlands elsewhere only once. The prominence of the goldfinch in the central Illinois list, (287 to the square mile), with only one record additional, is deceptive, being due to a single flock. Indeed, the actual numbers of birds seen in the woods of central and northern Illinois are so small (48 and 35 respectively) that the species ratios there have little meaning.

NUMBERS PER SQUARE MILE OF THE PRINCIPAL WINTER BIRDS IN WOODS

Species	Southern Illinois	Central Illinois	Northern Illinois	State
Quail	70	0	0	47
Turkey vulture	156	0	0	105
Downy woodpecker	27	*	66	29
Blue jay	162	13	11	113
Crow	37	118	164	74
Purple finch	40	0	0	27
Goldfinch	*	287	0	47
Tree sparrow	28	0	44	27
Slate-colored junco	431	0	0	289
Song sparrow	12	0	0	8
Cardinal	61	52	0	49
White-breasted nut-hatch	12	105	33	37
Tufted titmouse	131	*	0	90
Chickadee	0	39	66	19
Carolina chickadee	110	0	0	74
Bluebird	107	0	0	72
Total	1384	614	384	1107

* Number negligible.

The winter *orchard* area of thirty-eight acres was also too small for any but a few hints of general tendencies, that of northern Illinois being, in fact, quite negligible. Eighty birds of thirteen species were recorded from orchards, 65 of them (eleven species) being from southern Illinois, and 14 (five species) from central. Only the southern list has any special significance, and here juncos make up more than half the total number. Purple finches, field sparrows, and Carolina chickadees, next in order, were all seen the same number of times, and English sparrows and cardinals nearly as often. The general southern Illinois winter average was 2187 birds to the square mile of orchards, and of this number 1245 were juncos. The species were essentially those of the woodlands, only the English sparrow being reported from the orchard and not from the forest.

As is to be expected in winter when shelter is a prime necessity, our sixty-three acres of *shrubbery* contained more birds to the square mile

than any other habitat—2139 for the state at large and 2008 for southern Illinois, in which more than half of our shrubbery area was found. The central Illinois data are comparatively worthless because two flocks of English sparrows and chickadees respectively contained 73 of the 80 birds noted in the shrubbery of that section. English sparrows and quail numbered nearly half of all the birds of the state list in shrubbery, and the other more abundant species were chickadees, juncos, and blue jays, these five taken together making 82 per cent of all the shrubbery birds, leaving but 18 per cent for the other twelve species of the complete list. The special southern Illinois list—one made up, that is, of birds not seen in shrubbery farther north—comprises the quail, red-bellied woodpecker, purple finch, tree sparrow, junco, song sparrow, fox sparrow, tufted titmouse, Carolina chickadee, and bluebird—10 species out of 17 for the whole state.

NUMBERS PER SQUARE MILE OF ALL WINTER BIRDS FOUND IN SHRUBBERY

Species	Southern Illinois	Central Illinois	Northern Illinois	State
Quail	715	0	0	377*
Hairy woodpecker	0	0	71	20
Downy woodpecker	19	55	71	41
Red-bellied woodpecker	19	0	0	10
Blue jay	0	165	429	155*
Purple finch	174	0	0	93*
English sparrow	271	2744	0	653*
Tree sparrow	58	0	0	31
Slate-colored junco	464	0	0	248*
Song sparrow	38	0	0	20
Fox sparrow	58	0	0	31
Cardinal	19	55	0	20
White-breasted nuthatch	19	109	35	41
Tufted titmouse	38	0	0	20
Chickadee	0	1262	284	317*
Carolina chickadee	58	0	0	31
Bluebird	58	0	0	31
Total	2008	4390	890	2139

* The numbers starred make up 86 per cent of the total number of shrubbery birds in the state at large.

On our 250 acres of *waste and fallow* lands, 395 birds, representing nineteen species, were found,—equivalent to 1012 to the square mile. Much the most numerous of these were the gregarious tree sparrows and juncos, the latter about two-thirds as abundant as the former, (224 and 364 to the square mile respectively), the two together making 58 per cent. of the whole number of birds. All but one of the nineteen species were represented in the southern Illinois list as against 7 and 8

in central and northern Illinois or 10 in both sections together, leaving 9 species seen in southern Illinois and not farther north. Most of these, however, are usually to be found in central and northern Illinois in winter, but no doubt in smaller numbers than in the southern part of the state. As usual, the southern Illinois bird fauna was not only more diversified than the northern, but the leading species were each represented by a smaller number of birds. While three northern Illinois species were sufficient to make up 85 per cent of the whole number in that section and two central Illinois species were more than enough, eight were needed in southern Illinois—namely, the junco, quail, tree sparrow, song sparrow, blue jay, and cardinal and either the prairie horned lark, meadowlark, or bluebird.

NUMBERS PER SQUARE MILE OF ALL WINTER BIRDS IN WASTE AND FALLOW LANDS

Species	Southern Illinois	Central Illinois	Northern Illinois	State
Quail	127	199	72	115*
Red-tailed hawk	5	0	0	3
Hairy woodpecker	5	0	0	3
Downy woodpecker	17	36	7	15
Red-bellied woodpecker	11	0	0	6
Flicker	11	0	0	6
Prairie horned lark	22	0	0	12
Blue jay	88	0	13	46*
Crow	11	0	216	90*
Meadowlark	22	0	0	12
Tree sparrow	99	1121	405	364*
Slate-colored junco	225	470	70	224*
Song sparrow	99	54	13	60*
Swamp sparrow	5	0	0	3
Cardinal	66	72	0	48
White-breasted nuthatch	5	0	0	3
Tufted titmouse	17	36	0	13
Chickadee	0	0	39	15
Bluebird	22	0	0	10
Unrecognized	0	0	0	6
Total	857	1988	835	1054

* The numbers starred make up 85% of the entire number.

Our data for *yards and gardens* in winter call for bare mention only. On five northern Illinois patches so classed, amounting to $5\frac{3}{4}$ acres, the only birds were two chickadees, and these were in a hedge beside a barnyard and not in the yard itself. In $5\frac{1}{2}$ acres of central Illinois and $8\frac{1}{4}$ of southern, English sparrows, in numbers averaging about a dozen to the acre, were the only birds seen. A comparison of these numbers with those of the sparrow in other situations indicates that even in winter *Passer domesticus* is almost wholly a domestic species—3938 to

the square mile in the yards and gardens of the whole state in winter as compared with 653 to the square mile in shrubbery and 42 to the same area for the state as a whole.

THE SPRING MIGRATION PERIOD •

THE BIRDS OF MARCH, APRIL, AND MAY, 1907

The spring birds of each section of the state are divisible into permanent resident species, representatives of which remain in that section the year round; winter residents lingering for a time in the lap of spring; summer residents gradually arriving from the south; and migrant species which pass beyond the section to their breeding grounds farther north. As everything is in a state of flux from the beginning to the end of spring, and as the currents of bird life flowing northward are strongly influenced by highly variable local and temporary conditions, those of the weather especially, the product of our survey is like a moving picture rather than a stationary scene, and we can have no assurance that any feature of it will be definitely reproduced in any other year. A single season's record is, in its details, one sample only of many courses of events which may run through the same season of successive years; but even a single sample is doubtless to be preferred to none.

The state was incompletely covered in the spring of 1907 by four trips: one across its northern end from Waukegan to Scales Mound (March 2 to 15); two in central Illinois, from Bloomington to Champaign (March 19 to 21) and from Danville to Warsaw and thence back by a more southerly route (April 19 to May 31); and one along the eastern border from Harvey in Cook county to Brownsville in White county (March 26 to April 11). The whole distance thus traveled was 412.8 miles, and the birds were recognized and counted on areas amounting to 7858 acres, of which 1875 were in northern Illinois, 3923 in central, and 2060 along the eastern border. The central Illinois area was thus about equal to the two others taken together. The total of 7276 birds counted and listed belonged to 117 species, 23 of which were found on the first or northern trip, 108 on the two central Illinois trips, and 68 on the trips along the eastern border. Five of the northern Illinois species, 33 of the central section, and 21 of the eastern, contributed 85 per cent. of the total number of birds from their respective parts of the state. The numbers per square mile were 341 for northern, 547 for central, and 859 for eastern Illinois, with 593 to the square mile as an average for the whole area.

If we arrange the numbers of birds per square mile in the order of the successive dates of the four trips, we find them increasing rapidly from March 2 to April 5, but falling off in the period from April 20 to May 29 to approximately the same number as that for March 19 to 21. This may be taken as evidence of an increasing local density of the bird population as the wave of the spring migration proceeded north-

ward, birds from the south coming in more rapidly than winter residents left for the north, until about the middle of April, at which time the crest of the wave had passed on, to be followed by a downward slope in its rear as the winter residents hastened their departure and dwindling numbers of the latest migrants and the summer residents came in.

BIRDS PER SQUARE MILE IN SUCCESSIVE NORTHERN
AND CENTRAL ILLINOIS TRIPS,
SPRING OF 1907

March 2 to 15, Northern Illinois	394
March 19 to 21, Central Illinois	543
March 29 to April 5, Central Illinois	790
April 20 to May 29, Central Illinois	549

The details of the migration movement can best be shown by taking up the separate trips in order, and dividing the eastern Illinois trip from north to south into three sections corresponding to our usual divisions of the state. So proceeding, we shall have two sets of data for northern Illinois, three for central, and one for southern, the areas covered in these sections being respectively 2215, 5055, and 588 acres.

The most abundant species in northern Illinois at the time of the trip from Waukegan in Lake county to Scales Mound in Jo Daviess county (March 2-15) were the English sparrow, Lapland longspur, crow, prairie horned lark, and prairie hen, these together making up 85 per cent. of the whole number of birds. This is essentially a *winter list* to which small numbers of tree sparrows, juncos, and both varieties of horned larks may be added, together with woodpeckers, nuthatches, and an occasional hawk. The *spring migration* was represented by a few meadowlarks, rusty blackbirds, bronzed grackles, red-headed woodpeckers, bluebirds, robins, and mourning doves and a single song sparrow.

THE MOST ABUNDANT BIRDS (85 PER CENT. LIST), WAUKEGAN
TO SCALES MOUND, MARCH 2 TO 15, 1907

Species	No. of each	Ratio to total No.
English sparrow	475	41.2
Lapland longspur	188	16.3
Crow	151	13.1
Prairie horned lark	131	11.4
Prairie hen	42	3.6

All birds per square mile, 394.

Of the 1107 birds recognized, 846, or 77 per cent., belonged to species classed as permanent residents, 218, or 19.7 per cent. were winter residents, 3.3 per cent. were summer residents, recently arrived from the south, and 5 (rusty blackbirds), or less than one-half per cent., were migrants. The spring infiltration thus amounted to less than four

per cent. of the whole number identified. The English sparrows were much the most abundant, their number amounting to nearly 43 per cent. of all the birds seen on the trip across the northern end of the state. The prairie hen was represented by 42 birds, equal to 3.6 per cent. of the whole number listed.

RESIDENCE CLASSIFICATION, WAUKEGAN TO SCALES MOUND,
MARCH 2-15, 1907

NUMBER AND PER CENT OF SPECIES					
	<i>Permanent</i>	<i>Winter</i>	<i>Summer</i>	<i>Migrant</i>	<i>All</i>
Number	11	4	8	1	24
Per cent.	45.8	16.7	33.3	4.2	100

NUMBER AND PER CENT OF ALL BIRDS					
	<i>Permanent</i>	<i>Winter</i>	<i>Summer</i>	<i>Migrant</i>	<i>All</i>
Number	846	218	38	5	1107
Per cent.	76.4	19.7	3.3	0.6	100

NUMBER AND PER CENT OF NATIVES					
	<i>Permanent</i>	<i>Winter</i>	<i>Summer</i>	<i>Migrant</i>	<i>All</i>
Number	371	218	38	5	632
Per cent.	58.7	34.5	6.0	0.8	100

That the spring migration movement was in progress in extreme northern Illinois during this first half of March, 1907, may be seen by comparison of the *species ratios* of the residence classes of March 2-15 with those of January 2-16 as follows:

RATIOS OF SPECIES, NORTHERN ILLINOIS, WINTER AND SPRING				
	<i>Permanent</i>	<i>Winter</i>	<i>Summer</i>	<i>Migrant</i>
January 2-16	57.2	19.0	19.0	4.8
March 2-15	45.8	16.7	33.3	4.2

The sum of the ratios of permanent and winter resident species for the spring period is less by 14 than that for the winter period, and the summer resident species ratio is greater by the same amount. A comparison of the *numbers of native birds* in the several classes, gives much the same result, although the differences are less conspicuous. The permanent and winter total for January exceeds that for March by 5.2, and the summer and migrant total falls short the same number.

RATIOS OF NATIVE BIRDS, NORTHERN ILLINOIS, WINTER AND SPRING, 1907				
	<i>Permanent</i>	<i>Winter</i>	<i>Summer</i>	<i>Migrant</i>
January 2-16	61.4	37.0	1.3	0.3
March 2-15	58.7	34.5	6.0	0.8

From the foregoing statements, we may infer that certain species of permanent and winter residence had lost in the early spring so many of their numbers to the north that representatives of them were not found on the March trip across the northern end of the state, but that

other species of these classes had received accessions from the south in larger number than their losses by the northward movement.

The bird list of the short trip from Bloomington to Champaign (March 19-21) gave further evidence of the advent of spring in the addition of the red-winged blackbird to the list of summer residents, and the number of species necessary to make up the 85 per cent. list was also increased from five to fourteen. The prairie horned lark, rusty blackbird, junco, and meadowlark made up about half the total number, juncos and tree sparrows remaining to represent the winter residents. Much more definite evidence of the increased effect of spring conditions is given by the ratios of the several residence classes as compared with those just given. Against 3.3 per cent of summer residents and less than 1 per cent of migrants for the first half of March in northern Illinois, we now have 30.9 per cent. of summer residents and 14.4 per cent. of migrants during the second half of the month in central Illinois, while the winter residents remaining were 19.7 per cent. northern and 16.6 per cent. central. The ratio of spring arrivals (summer residents and migrants) on the central Illinois list was thus more than ten times that of the slightly earlier northern Illinois list, the ratio of winter residents being at the same time less than a sixth smaller—another illustration of the fact previously referred to that birds from the south come up in the spring migration earlier and in much larger numbers than those of the northern birds which are leaving for their summer homes, with the result that a wave of condensation rolls northward, to be followed presently, like any other wave, by a “trough” of diminished numbers.

RESIDENCE RATIOS, NUMBERS OF BIRDS

	<i>Permanent</i>	<i>Winter</i>	<i>Summer</i>	<i>Migrant</i>
Northern Illinois, March 2-15	76.4	19.7	3.3	0.6
Central Illinois, March 19-21	38.1	16.6	30.9	14.4

THE MOST ABUNDANT BIRDS (85 PER CENT. LIST), BLOOMINGTON TO CHAMPAIGN, MARCH 19 TO 21, 1907

Species	No. of each	Ratio to total No.
Prairie horned lark	82	14.
Rusty blackbird	75	12.8
Junco	67	11.5
Meadowlark	57	9.8
English sparrow	32	5.5
Bronzed grackle	28	4.8
Crow	25	4.3
Bluebird	25	4.3
Tree sparrow	24	4.1
Red-winged blackbird	22	3.8
Song sparrow	19	3.3
Flicker	17	2.9
Robin	14	2.4
Prairie hen	13	2.2

All birds per square mile, 543.

If we divide the eastern Illinois trip (113.4 miles) into three sections corresponding to the divisions of the state, we find that in the northern Illinois section from Harvey to Grant Park, (March 26 to 28), three of the most abundant species (Lapland longspur, English sparrow, and prairie horned lark) were winter birds which together made up about 54 per cent of the 559 birds seen, and that the Lapland longspur stands at the head of the list. Other winter species still lingering in small numbers were the junco, Smith's longspur, and tree sparrow, but a much larger number of the following species, mentioned herein in a diminishing order of numbers, had already come up from the south, viz., meadowlark, Wilson's snipe, rusty blackbird, Canada goose, bronzed grackle, robin, red-winged blackbird, vesper sparrow, migrant shrike, killdeer, cowbird, pintail duck, and phoebe.

It has often been noticed that birds in migration concentrate at the southern end of Lake Michigan, passing thence northward along the western shore as by a high road, and an unusual number of birds were found in this northern section of eighteen miles. These were mainly a flock of thirty-two Canada geese seen in a muddy pond in a plowed field, several small flocks of Wilson's snipe, and large numbers of Lapland longspurs still remaining, and of meadowlarks, prairie horned larks, and rusty blackbirds, all of which taken together made up 731 of the 1061 birds to the square mile recorded from this northern section of the trip.

Of the 24 species recognized, 14 were summer residents, 2 were migrants, 5 were permanent residents, and only 3 were winter residents; or, taking account of the actual numbers of birds seen, 32 per cent were summer residents, 34 per cent were winter residents, 27 per cent were permanent residents, and 7 per cent were migrants.

RESIDENCE CLASSIFICATION OF SPECIES, NORTHERN ILLINOIS,
HARVEY TO GRANT PARK

MARCH 26 TO 28, 1907, EASTERN ILLINOIS TRIP

<i>Species</i>	<i>Permanent</i>	<i>Winter</i>	<i>Summer</i>	<i>Migrants</i>	<i>All</i>
Numbers	5	3	14	2	24
Per cent.	20.8	12.5	58.3	8.4	100

NUMBERS AND PER CENTS OF ALL BIRDS

Numbers	150	190	179	40	559
Per cent.	26.8	34.0	32.0	7.2	100

NUMBERS AND PER CENTS OF NATIVE BIRDS

Numbers	83	190	179	40	492
Per cent.	16.9	38.6	36.4	8.1	100

NUMBERS OF THE MORE ABUNDANT SPECIES. HARVEY TO
GRANT PARK, MARCH 26 TO 28, 1907

	No. of each	Ratio to total No.
Lapland longspur	182	32%
English sparrow	67	12
Meadowlark	51	9
Prairie horned lark	46	9
Wilson's snipe	45	9
Canada goose	32	6
Rusty blackbird	32	6
Bronzed grackle	14	2
Prairie hen	13	2

All birds, 1961 to the square mile.

In the central Illinois division, (March 29 to April 5) the number of birds to the square mile (719) was only 70 per cent that in the northern division, although the number of species was more than twice as large (54 for central and 24 for northern). Of winter residents there still remained the Lapland longspur, tree sparrow, junco, and golden-crowned kinglet, which taken together made less than 10 per cent of the birds of the area. The summer birds had already come to predominate in this transition period, and the total number of birds per square mile recorded on this central Illinois trip (719) was much above the average of this region for the winter season, (440), and greater even than the July average (650) of the same year. If, however, we take into consideration the permanent and summer residents only, we see that the summer population had not yet arrived in full strength, the total number averaging only 445 to the square mile. The crest of the spring wave already referred to was thus made up of all four of the residence classes in the ratio of 23% of permanent residents, 9% of winter residents, 30% of migrants and 38% of summer residents. If we omit the English sparrows, the corresponding residence ratios are permanent 17%, winter 10%, summer 41%, and migrant 33%.

RESIDENCE CLASSIFICATION, CENTRAL ILLINOIS, SPRING, MARCH
29—APRIL 5, WATSEKA TO FLAT ROCK, EASTERN
ILLINOIS (CENTRAL)

NUMBERS AND PER CENTS OF SPECIES

	<i>Permanent</i>	<i>Winter</i>	<i>Summer</i>	<i>Migrants</i>	<i>All</i>
Numbers	19	4	20	11	54
Per cent.	35.2	7.4	37.0	20.4	100

NUMBERS AND PER CENTS OF ALL BIRDS

Numbers	289	115	489	392	1294
Per cent.	23.0	8.9	37.8	30.3	100

NUMBERS AND PER CENTS OF NATIVE BIRDS

Numbers	207	115	489	392	1203
Per cent.	17.2	9.6	40.6	32.6	100

NUMBERS OF THE MORE ABUNDANT BIRDS, WATSEKA TO
FLAT ROCK, MARCH 29 TO APRIL 5, 1907

	No. of each	Ratio to total No.
Meadowlark	175	13.6
Buff-breasted sandpiper	170	13.2
Smith's longspur	96	7.4
English sparrow	91	7.0
Pipit	82	6.3
Field sparrow	78	....
Bluebird	68	5.3
Vesper sparrow	58	4.5
Lapland longspur	55	4.3
Junco	52	4.0
Flicker	48	3.7
Prairie horned lark	39	3.0
Mourning dove	28	2.2
Robin	22	1.7
Crow	21	1.6
Cowbird	20	1.5
Crow blackbird	15	1.2
Savannah sparrow	15	1.2
All birds per square mile	719	

Turning now to the southern Illinois division (April 6 to 11) of the eastern Illinois trip, we find that although the number of species recorded was the same as for central Illinois, the effect of a lower latitude and slightly later date is shown in a number of birds, (1004 to the square mile), 37 per cent larger than that of the central Illinois list of the week before, and materially larger than that of the summer seasons of 1907 and 1909 (925 to the square mile). The principal winter species remaining were the savannah sparrow and juncos, and there was also a sprinkling of tree sparrows, golden-crowned kinglets, and four other species to be classed as winter birds in southern Illinois, the total number of this class amounting to 12 per cent of all the birds seen. 5.7 per cent were of migrant species, of which the pipit was much the most abundant, but about four-fifths of these April birds were permanent or summer residents, 65.5 per cent of the first and 15.7 per cent of the second. The ratio of permanent residents was nearly as large as in the dead of winter (see p. 403) and the 31 per cent of winter residents of that season were now represented by 12 per cent., the remainder being replaced by migrants and summer residents.

RESIDENCE CLASSIFICATION, SOUTHERN ILLINOIS, LAWRENCEVILLE
TO BROWNSVILLE, APRIL 6-11, 1907

NUMBERS AND PER CENTS OF SPECIES

	<i>Permanent</i>	<i>Winter</i>	<i>Summer</i>	<i>Migrants</i>	<i>All</i>
Numbers	28	8	10	8	54
Per cent.	51.9	14.8	18.5	14.8	100.0

NUMBERS AND PER CENTS OF ALL BIRDS

Numbers	601	109	140	52	902
Per cent.	66.6	12.1	15.5	5.8	100.0

NUMBERS AND PER CENTS OF NATIVES

Numbers	571	109	140	52	872
Per cent.	65.5	12.5	16.0	6.0	100.0

NUMBERS OF THE MORE ABUNDANT BIRDS, LAWRENCEVILLE
TO BROWNSVILLE, APRIL 6 TO 11, 1907

	No. of each	Ratio to total No.
Meadowlark	124	13.4
Bronzed grackle	87	9.4
Field sparrow	72	7.8
Quail	65	7.0
Cowbird	64	6.9
Savannah sparrow	63	6.8
Mourning dove	51	5.5
Vesper sparrow	37	4.0
Pipit	32	3.5
Junco	31	3.4
English sparrow	30	3.3
Robin	26	2.8
Flicker	22	2.4
Goldfinch	20	2.2
Blue jay	16	1.7
Bluebird	15	1.6
Cardinal	14	1.5
Towhee	12	1.3
Crow	11	1.2
Tufted titmouse	10	1.1
		85% = 785
All birds to the square mile	1007	

The fourth and longest trip of the spring of 1907, made April 20 to May 29, crossed the state from Danville to Warsaw by way of Clinton, Havana, Burnside, and Hamilton, and dropped back thence by rail to Lincoln, whence it returned to Danville by Clinton and Urbana, with an excursion from this last point south to Tuscola. The distance traveled was 180.6 miles and the area covered was 3235.17 acres, from which record was made of 2773 birds (549 to the square mile) belonging to 97 species. Eighty-three per cent. of the acreage was in oats (22.6 per cent.), plowed ground (21.7 per cent.), corn (20.6 per cent.), and

pasture (18.1 per cent.), the remainder being in wheat, stubble, meadows, woods, and waste land, with very small tracts of shrubbery, orchards, and farmyards.

Twenty-nine of the species of birds gave us 85 per cent. of the whole number, an average of 81 birds to the species, the remaining 68 species averaging only 6 birds each. A third of all the birds belonged, in fact, to four species, the English sparrow, bronzed grackle, meadow-lark, and prairie horned lark; and if to these we add three more, the golden plover, robin, and cowbird, we have nearly half the whole number. Eighteen Smith's longspurs and 23 juncos were the only representatives of the winter-resident group found still lingering in central Illinois, the juncos seen April 23 and 26 and the longspurs May 1. Twenty of the 97 species noted were migrants on their way to points beyond our area, leaving 75 species normal to the summer season in central Illinois. Stated in numbers of birds, 0.9 per cent of those seen on these forty days of late April and May were winter residents, 14.5 per cent. were migrants, and 84.6 per cent. were summer birds, including permanent residents.

RESIDENCE CLASSIFICATION, SPRING 1907, APRIL 20—MAY 29,
CENTRAL ILLINOIS

NUMBERS AND PER CENTS OF SPECIES					
	<i>Permanent</i>	<i>Winter</i>	<i>Summer</i>	<i>Migrant</i>	<i>All</i>
Numbers	16	1	54	25	96
Per cent.	16.7	1.0	56.3	26.0	100

NUMBERS AND PER CENTS OF ALL BIRDS					
	<i>Permanent</i>	<i>Winter</i>	<i>Summer</i>	<i>Migrant</i>	<i>All</i>
Numbers	803	23	1464	389	2679
Per cent.	30.1	0.9	54.5	14.5	100

NUMBERS OF NATIVE BIRDS AND PER CENTS					
	<i>Permanent</i>	<i>Winter</i>	<i>Summer</i>	<i>Migrant</i>	<i>All</i>
Numbers	537	23	1464	389	2413
Per cent.	22.3	0.9	60.7	16.1	100

That spring was now nearly merged in summer is further shown by a comparison of the present 85 per cent. list with the corresponding central Illinois list for July 1907, from which it appears that all the twelve birds of the latter list are among the first thirteen of the former. That the movement northward of these characteristic and dominant summer species was, however, far from complete seems probable from the fact that their total number averaged 553 to the square mile for July, 1907, and only 319 to the mile for April and May of the same year. But 58 per cent. of what we may call the final summer number of the birds of these species were on the ground by the end of May. Just what this difference may mean, however, it is impossible to say, since the summer average covers some of the young of the year, (of the number of which we have no record), as well as later accessions from the south.

SPRING BIRDS IN HABITATS

The difficulty of determining the habitat preferences of a faunal group as sensitive to environmental conditions, as alert in readjustment, and as capable of free and rapid locomotion as birds, is very great even in the comparatively stable summer season when their obligations to their young anchor them to their chosen breeding places; and it is many times multiplied when the period of their migration converts the semi-stagnant pool of bird life into a swirling stream whose very banks change and shift from day to day as the season advances. Our tabulated data of numbers per square mile in different habitats during the spring migration give us, therefore, little that is worthy of record. A few tentative generalizations may be made, however, from a comparison of numbers in the principal central Illinois habitats in April and May, 1907, with those of July of the same year. That the number of mourning doves in wheat should be 22 to the square mile in spring and 313 in July, and that the number of the most abundant birds per square mile of wheat should be 360 in spring and 837 in summer, can be readily understood as due to the food resources offered to birds in the fields of shocked grain.

Of the seven areas large enough to appear in our central Illinois averages of the late spring, pastures and meadows were much the most thickly populated (1091 and 1086 to the square mile respectively), and stubble field were next (877 to the mile), while corn, wheat, oats, and plowed ground were curiously similar in their averages to the square mile, (312, 363, 302, and 332). These last figures perhaps express the numbers attributable to a mere chance distribution of birds not yet settled for the summer season, and the large numbers for pastures and meadows may be taken as evidence of a choice of habitats most nearly like the original prairie of central Illinois. Their preponderance is further shown by the fact that it was true not only for birds in general but also for 14 of the 18 species on our most abundant list. Our woodland area of only $43\frac{1}{2}$ acres is too small for satisfactory inference, especially as only eight of our 18 more abundant birds were found there; but these were numerous enough to give us an average of 1487 per square mile. Only three of them, however, were characteristically woodland species, and this average and also the even less dependable ones of still smaller tracts of orchards, shrubbery, and yards and gardens had probably best be ignored.

THE FALL MIGRATION PERIOD

Our available data of the fall migration period were obtained in 1906 in central and southern Illinois only, in the former from August 29 to October 26 inclusive, and in the latter from October 31 to November 16. In central Illinois trips were made from Urbana past Danville to the Indiana line, August 29 to September 1, from Cham-

paign to Downs in McLean county, September 4 to 7, from Champaign across the state by way of Decatur and Jacksonville to Quincy on the Mississippi River, September 17 to October 17, and for short distances about Urbana, September 12 to 15 and October 23 to 26. In southern Illinois a single trip was made from Cairo northward to Pana. The area surveyed in these periods was 5,890.58 acres, of which 70 per cent. was in central Illinois. On this entire area 9,387 birds were recognized and counted (1020 to the square mile), 5,408 of them in central Illinois, and 3,979 in southern. The number per square mile in central Illinois was only two-thirds of that in southern (883 to 1467), a difference at least partially attributable, no doubt, to the later period of the summer observations and the concentration there of birds in the act of migration.

The percents of permanent and winter resident *species*, taken together, were in early November about three times as large in southern Illinois as in central in September and October, and those of the summer and migrant species were about three times as large in central Illinois as in southern. In *numbers of native birds* the permanent and winter residents together were nearly twice as abundant south as north, and the summer residents and migrants were about twice as abundant north as south. The great predominance of English sparrows in central Illinois, as compared with southern, obscures the contrast in the numbers of the table of *all birds* by its over-weight of permanent residents in the central section.

RESIDENCE CLASSIFICATION, FALL, CENTRAL ILLINOIS, AUGUST 28
TO OCTOBER 26, 1906

NUMBERS AND PER CENTS OF SPECIES

	<i>Permanent</i>	<i>Winter</i>	<i>Summer</i>	<i>Migrants</i>	<i>All</i>
Numbers	21	6	51	24	102
Per cent.	20.6	5.9	50.0	23.5	100

NUMBERS AND PER CENTS OF ALL BIRDS

	<i>Permanent</i>	<i>Winter</i>	<i>Summer</i>	<i>Migrants</i>	<i>All</i>
Numbers	3367	270	2161	553	6351
Per cent.	53.0	4.3	34.0	8.7	100

NUMBERS AND PER CENTS OF NATIVE BIRDS

	<i>Permanent</i>	<i>Winter</i>	<i>Summer</i>	<i>Migrants</i>	<i>All</i>
Numbers	1263	270	2161	553	4247
Per cent.	29.7	6.4	50.9	13.0	100

RESIDENCE CLASSIFICATION, FALL, SOUTHERN ILLINOIS, OCTOBER
31 TO NOVEMBER 16

NUMBERS AND PER CENTS OF SPECIES

	<i>Permanent</i>	<i>Winter</i>	<i>Summer</i>	<i>Migrants</i>	<i>All</i>
Numbers	32	9	8	7	56
Per cent.	57.2	16.1	14.2	12.5	100

NUMBERS AND PER CENTS OF ALL BIRDS

	<i>Permanent</i>	<i>Winter</i>	<i>Summer</i>	<i>Migrants</i>	<i>All</i>
Numbers	2034	875	936	124	3969
Per cent.	51.2	22.1	23.6	3.1	100

NUMBERS AND PER CENTS OF NATIVE BIRDS

	<i>Permanent</i>	<i>Winter</i>	<i>Summer</i>	<i>Migrants</i>	<i>All</i>
Numbers	1961	875	936	124	3896
Per cent.	50.3	22.5	24.0	3.2	100

RESIDENCE CLASSIFICATION RATIOS, FALL PERIOD, CENTRAL AND SOUTHERN ILLINOIS COMPARED

SPECIES

	<i>Permanent</i>	<i>Winter</i>	<i>Summer</i>	<i>Migrants</i>
Central Illinois	20.6	5.9	50.0	23.5
Southern Illinois	57.2	16.1	14.2	12.5

NUMBERS OF ALL BIRDS

Central Illinois	53.0	4.3	34.0	8.7
Southern Illinois	51.2	22.1	23.6	3.1

NUMBERS OF NATIVES

Central Illinois	29.7	6.4	50.9	13.0
Southern Illinois	50.3	22.5	24.0	3.2

The large ratios of permanent resident species and native birds in southern Illinois is of course attributable to the fact that many species of general summer distribution are driven by the cold from the northern sections into, but not beyond, the southern part of the state; and other differences are doubtless due in part to an advancement of the season by about six weeks when the southern Illinois observations were made.

The southward concentration already referred to is most clearly shown by a tabulation of species and numbers of the fall birds of central Illinois which were found also in southern Illinois in fall. Such a list comprised 48 native species, and the total number of birds of these species seen and counted in central Illinois was 3,919, and in southern Illinois 3,844,—equivalent to an average of 608 to the square mile for central and 1,392 for southern Illinois. That is, relatively late fall birds of southern Illinois were nearly $2\frac{1}{2}$ times as abundant to the unit of area as the somewhat earlier birds of the central Illinois fall. The greater abundance of birds in southern Illinois in winter than in summer referred to on page 421 was thus already well marked in the latter part of the migration season.

The stage of migration covered by these observations can be told by comparing the numbers of birds of definitely transient species (that is summer residents and migrants) on the fall lists for central and southern Illinois respectively, which were found in both sections of the state. So doing, we find 11 such species in which central Illinois numbers per square mile exceeded those for southern Illinois and 19 in

which southern Illinois numbers exceeded the central Illinois. In the former group migration was at best only beginning when the central Illinois observations were made, but in the latter it was at least well under way and may have passed its climax at the time of the southern Illinois observations.

NATIVE SPECIES COMMON TO CENTRAL AND SOUTHERN
ILLINOIS, FALL OF 1906

	Central	Southern**
Killdeer	70	6+
Quail	72	365*
Prairie chicken	12	19*
Mourning dove	207	30*
Turkey vulture	7	8+
Marsh hawk	3	1*
Red-tailed hawk	4	5*
Pigeon hawk	1	1+
Sparrow hawk	9	6+
Downy woodpecker	11	26*
Red-headed woodpecker	31	4+
Flicker	86	41*
Prairie horned lark	329	104*
Blue jay	71	38*
Crow	243	380*
Cowbird	365	6+
Red-winged blackbird	16	2+
Meadowlark	377	128+
Rusty blackbird	20	8+
Bronzed grackle	677	862+
Goldfinch	144	97*
Vesper sparrow	82	3+
Savannah sparrow	9	13+
Grasshopper sparrow	67	1+
Henslow's sparrow	2	1+
White-crowned sparrow	8	2+
White-throated sparrow	93	156+
Tree sparrow	10	20+
Chipping sparrow	4	5+
Field sparrow	84	58+
Slate-colored junco	238	624+
Song sparrow	30	85*
Lincoln's sparrow	6	1+
Swamp sparrow	157	46+
Fox sparrow	8	14+
Towhee	15	6+
Cardinal	3	42*
Migrant shrike	6	4*
Myrtle warbler	112	30+
Pipit	48	68+
Mockingbird	2	9+

* Not transient in central and southern Illinois.

+ Transient in central and southern Illinois.

** To adjust these numbers for comparison, multiply those for southern Illinois by $2\frac{1}{2}$.

NATIVE SPECIES COMMON TO CENTRAL AND SOUTHERN
ILLINOIS, FALL OF 1906—*Concluded*

	Central	Southern**
Bewick's wren	1	1+
White-breasted nuthatch	2	2*
Tufted titmouse	10	16*
Carolina chickadee	7	33*
Golden-crowned kinglet	12	1+
Robin	87	393+
Bluebird	61	84+
English Sparrow	3919	3844
	2104	73

* Not transient in central and southern Illinois.

+ Transient in central and southern Illinois.

** To adjust these numbers for comparison, multiply those for southern Illinois by $2\frac{1}{4}$.

In the trip across the central part of Illinois, made August 28 to October 29, 6382 birds were seen and counted, 31 of them not recognized and the remainder belonging to 102 species. Seventeen of the more abundant kinds made up 85 per cent of the whole number, with an average of 321 birds to the species, the remaining 85 species averaging but 11 birds each. An enormous abundance of English sparrows, amounting to 38.6% of the whole number of birds seen and counted, reduces the number of native birds to 4278, 21 species of which, with an average of 204 birds, were on the 85% list, the remaining 80 species averaging 8 birds each.

Among the more obvious evidences of migration shown by the following table of the more abundant central Illinois species is the occurrence of considerable numbers of juncos, myrtle warblers, white-throated sparrows, and pipits, but the general composition of the list is still that of the summer birds.

NUMBERS OF THE MORE ABUNDANT BIRDS OF CENTRAL ILLINOIS, FALL OF 1906
(AUGUST 29 TO OCTOBER 26) 85% LIST

English sparrow	2104	Goldfinch	144
Bronzed grackle	677	Myrtle warbler	112
Meadowlark	377	White-throated sparrow	93
Cowbird	365	Robin	87
Prairie horned lark	329	Flicker	86
Crow	243	Field sparrow	84
Slate-colored junco	238	Vesper sparrow	82
Mourning dove	207	Quail	72
Swamp sparrow	157		

ADDITIONAL SPECIES, IF ENGLISH SPARROWS ARE ELIMINATED

Blue jay	71	Bluebird	61
Killdeer	70	Pipit	48
Grasshopper sparrow	67		

On the much smaller area of southern Illinois surveyed October 21 to November 16 (acreage for central Illinois 4623.7, for southern Illinois 1763.42), but 56 species were listed (3979 birds) the following 13 of which were needed to include 85% of the whole number.

NUMBERS OF THE MORE ABUNDANT BIRDS OF SOUTHERN ILLINOIS, FALL OF 1906
(OCTOBER 31 TO NOVEMBER 16) 85% LIST

Bronzed grackle	862	Prairie horned lark	104
Slate-colored junco	624	Goldfinch	97
Robin	393	Song sparrow	85
Crow	380	Bluebird	84
Quail	365	English sparrow	73
White-throated sparrow	156	Pipit	68
Meadowlark	128		

English sparrows, it will be seen, contributed less than 2% to the total. The 13 more abundant species averaged 263 each, and the remaining 43 species 13 each. The above list differs from that of central Illinois for September and October by the dropping of seven species and the addition of the song sparrow, and in the order of abundance of the numbers of birds the several species common to the lists, of course, differ widely. The most notable difference is in the numbers of the English sparrow, which drops from the head of the list in central Illinois to the next to the last place on that for southern Illinois. The junco, robin, and quail were especially more abundant southward, but the general composition of the two lists is fairly similar.

FALL BIRDS IN HABITATS

The relation of birds to special features of their environment during the migration period, characterized as this is by a breaking of the ties which have held the birds to their local habitats during summer or winter, is necessarily of relatively little moment except as it may tend to show a persistence of features of their habitat choices which even the abandonment of their previous homes in a search for new situations can not wholly dissolve. It may be, also, that the exigencies of migration involve different demands and hence different habitat resorts from those of a settled and relatively solitary life.

Certainly our tabulation of the numbers of birds per square mile in the several habitats of central Illinois in autumn gives color to this latter supposition. Among all the situations offered by the open fields, the pasture contained more than twice as many birds to the mile as any other, notwithstanding the fact that its total area was next to the largest on the list. Only corn surpassed it in area, and pastures contained two and a half times as many birds to the mile as corn.

ALL BIRDS IN HABITATS, FALL OF 1906, CENTRAL ILLINOIS

	Acreage	Nos. Birds	Birds per sq. mi.
Corn	1745.17	1617	593
Wheat	163.68	46	180
Stubble	952.87	573	385
Pasture	1198.47	2787	1490
Meadows	216.23	212	628
Plowed ground	166.61	171	657
Orchards	51.54	212	2633
Woods	11.48	22	1226
Shrubbery	10.60	63	3804
Yards and gardens	37.60	155	2638
Waste and fallow	65.45	462	4518
Miscellaneous	4.00	62	9920
Open fields	4443.03	5406	779
Woods, etc.	180.67	976	3457

On a fifth part of the area of pastures, meadows had less than half as many birds to the square mile, and plowed ground had nearly the same number per square mile as meadows. Young wheat, after the plant has started to grow, has evidently very little to offer the migrating bird, or to the fall resident, for that matter, but stubble fields doubtless offer some food. The especially striking feature of the situation is the very extraordinary number of birds found on all tracts covered by trees, shrubbery, and other rank vegetation like that of waste and fallow lands. Our areas of orchards, woods, shrubbery, yards and gardens, and wastes and fallows, are severally too small to have much meaning, notwithstanding a density of bird life in all ranging from 1226 to 4518 per square mile; but if we throw these tracts together into one fairly adequate total of 180.7 acres, we have an average density of 3457 birds to the square mile for the whole area as compared with 1490 for the very attractive pastures or 779 to the square mile for 4443 acres of open fields. Food in the pastures and both food and sheltered resting places in the other situations after the fatigues of their migration flights perhaps account for both these choices.

Our table of birds per square mile in fall in southern Illinois habitats is so distorted by the occurrence of large flocks of crows and black-birds in corn, stubble, and woods that these must be eliminated to give us numbers comparable with those of central Illinois. This being done, we have in the two sections the same distinction between numbers of birds in the open fields and those in trees and shrubbery—that is woods, orchards, shrubbery, waste and fallow lands, and yards and gardens; the former averaging 621 birds per square mile on an area of 1439 acres and the latter averaging 2365 per square mile on a total of 401.5 acres. Wheat was in both sections visited by the smallest numbers of birds, but corn fields surpassed pastures in southern Illinois in the numbers resorting to them.

In corn fields, quails, crow blackbirds, and robins were the most abundant species; in wheat, only prairie horned larks were common enough to call for special mention; in stubble, blackbirds and crows were in a large majority; in pastures, only juncos were notably above the average; in meadows, meadowlarks, robins, and quail were the principal species; and those on plowed ground were juncos and prairie horned larks; in orchards, the junco greatly outnumbered all others; and in woods, robins, blackbirds, white-throated sparrows and juncos were the most abundant species—all data of observation, correct for the time and place, but furnishing, so far as we can see, no obvious warrant for generalization or prediction. Our fall habitat lists of central and southern Illinois have little resemblance, as was to be expected in view of the differences in climate, topography, and the date of observations made in the two sections.

ALL BIRDS IN HABITATS, FALL OF 1906, SOUTHERN ILLINOIS

	Acres	Nos. of birds	Birds per sq. mi.
Corn	301.46	573 (462)	1216 (981)
Wheat	177.70	30	108
Stubble	178.98	1116 (195)	4000 (697)
Pasture	301.23	309	657
Meadow	302.15	213	451
Plowed ground	87.85	101	736
Orchards	131.94	322	1562
Woods	84.19	842 (692)	6401 (5266)
Shrubbery	18.54	45	1553
Yards and gardens	49.63	42	542
Waste and fallow	117.22	383	2091
Miscellaneous	12.53	3	153

NOTE: Figures in parenthesis are remainders after subtracting crows and bronzed grackles.

GENERAL SUMMARY OF THE MORE ABUNDANT BIRDS

We have repeatedly shown that relatively few species are represented in a single region or habitat by a sufficient number of birds to have any important effect, ecological or economic, and that more species consequently signify little or nothing in the system of life at the time and place; but in this connection account must be taken of the fact that species insignificant in one environment may be of primary importance in another and that a complete list of those important in some situation or relationship is needed to give an adequate idea of the significance of birds as a class. As a contribution to such a list of Illinois birds present

somewhere in really dominant numbers, we have made general tables of all the species which are on the "more abundant" lists of any section of the state in summer or in winter and of the more abundant species in any one of our thirteen habitats in either of these seasons. We have omitted from this tabulation the birds of spring and fall because of the brief periods of residence of many species and the extremely variable numbers of birds in any environment during the migration seasons.

Taking up first the geographical divisions, we find that of the 83 species of counted birds on our southern Illinois summer list, 22 were in our "more abundant" group and of the 41 winter species of that section, 14 were relatively abundant. The corresponding numbers of species for central Illinois were 68 and 13 respectively in summer and 27 and 6 respectively in winter, and for northern Illinois they were 95 and 15 in summer and 32 and 6 in winter. In our list for the state as a whole, we have 113 summer species on record of which 28 were classed as abundant, and 49 winter species 17 of which were abundant; that is, grouped geographically and seasonally from 16 to 35 per cent of our species fell in some one or more of our 85 per cent lists under these heads.

• MORE ABUNDANT SUMMER AND WINTER BIRDS BY SECTIONS OF THE STATE

	<i>Summer</i>			<i>Winter</i>		
	S	C	N	S	C	N
Killdeer	X	—	—	—	—	—
Bob-white	X	—	—	X	—	—
Mourning dove	X	X	X	X	—	—
Turkey vulture	—	—	—	X	—	—
Red-headed woodpecker	X	X	—	—	—	—
Flicker	X	X	X	—	—	—
Kingbird	X	—	—	—	—	—
Prairie horned lark	—	X	X	X	X	X
Blue jay	X	—	—	X	—	—
American crow	—	X	X	—	X	X
Bobolink	—	—	X	—	—	—
Cowbird	X	X	—	—	—	—
Red-winged blackbird	X	X	X	—	—	—
Meadowlark	X	X	X	X	—	—
Orchard oriole	X	—	—	—	—	—
Bronzed grackle	X	X	X	—	—	—
Purple finch	—	—	—	X	—	—
American goldfinch	—	—	X	—	X	X
English sparrow	X	X	X	—	X	X
Lapland longspur	—	—	—	—	—	X
Vesper sparrow	—	—	X	—	—	—
Grasshopper sparrow	—	—	X	—	—	—
Lark sparrow	X	—	—	—	—	—
Tree sparrow	—	—	—	X	X	X
Field sparrow	X	—	—	—	—	—
Slate-colored junco	—	—	—	X	X	—
Song sparrow	—	—	—	X	—	—

MORE ABUNDANT SUMMER AND WINTER BIRDS BY SECTIONS OF THE STATE—*Concluded*

	Summer			Winter		
	S	C	N	S	C	N
Cardinal	—	—	—	X	—	—
Indigo bunting	X	—	—	—	—	—
Dickcissel	X	X	X	—	—	—
Barn swallow	—	—	X	—	—	—
Maryland yellow-throat	X	—	—	—	—	—
Mockingbird	X	—	—	—	—	—
Brown thrasher	X	X	—	—	—	—
Tufted titmouse	—	—	—	X	—	—
Carolina chickadee	—	—	—	X	—	—
American robin	X	X	X	—	—	—
Bluebird	X	—	—	X	—	—
38 Species	22	13	15	14	6	6

Our habitat tables, on the other hand, show that of 113 summer species 48 were found on the 85 per cent list of one or more habitats and that of the 49 winter species 29 were on at least one of the 85 per cent. lists—ratios of 42 per cent. and 60 per cent. respectively.

NUMBERS AND RATIOS OF SPECIES OF MORE
ABUNDANT BIRDS, BY SEASONS, SEC-
TIONS, AND HABITATS

SOUTHERN ILLINOIS			
	Total number	85 per cent. list	Ratios per cent.
Summer	83	22	27
Winter	41	14	34
CENTRAL ILLINOIS			
Summer	68	13	18
Winter	27	6	22
NORTHERN ILLINOIS			
Summer	95	15	16
Winter	32	6	19
WHOLE STATE			
Summer	113	28	25
Winter	49	17	35
HABITAT RATIOS			
Summer	113	48	42
Winter	49	29	60

The total number of species counted and recorded on our two lists of seasons and habitats is 125 and the number on the corresponding two "more abundant" lists is 63; that is, 50 per cent. of these species were found sufficiently abundant in some sectional or habitat situation to bring them into one or more of our "more abundant" groups. To this 50 per cent we would add, if we could, a variable and unknown number of spring and fall migrants which remain in the state long enough to en-

MORE ABUNDANT SUMMER BIRDS, WHOLE STATE, BY HABITATS

The figures at the heads of the columns on the habitat table have the following meanings:

(1) Meadow; (2) pasture; (3) swamp; (4) waste and fallow; (5) wheat, rye, or barley; (6) oats; (7) corn; (8) stubble of small grain; (9) plowed ground; (10) woods; (11) orchard; (12) shrubbery; (13) yards and gardens.

A. O. U. Nos.	1	2	3	4	5	6	7	8	9	10	11	12	13
201	—	—	X	—	—	—	—	—	—	—	—	—	—
261	X	—	—	—	—	—	—	—	X	—	—	—	—
273	—	—	—	—	—	—	—	—	X	—	—	—	—
289	—	X	X	—	—	X	X	—	—	X	X	X	—
316	X	X	—	X	X	X	X	X	X	X	X	X	—
325	—	—	—	—	—	—	—	—	—	X	—	—	—
360	—	—	—	—	—	—	—	—	—	X	—	—	—
393	—	—	—	—	—	—	—	—	—	X	—	—	—
406	—	X	—	X	—	—	X	—	—	X	—	X	—
412	X	X	—	—	—	—	X	—	—	X	X	—	—
444	X	X	—	X	—	—	—	—	—	X	—	X	—
452	—	—	—	—	—	—	—	—	—	X	—	—	—
456	—	—	—	—	—	—	—	—	—	X	—	—	—
463	—	—	—	—	—	—	—	—	—	X	—	—	—
474b	X	X	—	—	X	X	X	X	X	—	—	—	—
477	—	—	—	X	—	—	—	—	—	X	X	X	—
488	—	X	—	X	X	X	X	X	—	X	—	X	—
494	X	X	X	X	—	X	X	X	—	—	—	—	—
495	—	X	X	—	X	X	X	—	X	X	—	X	X
498	X	X	—	X	X	X	X	—	—	X	—	—	—
501	X	X	X	X	X	X	X	X	X	—	—	X	X
506	—	—	—	—	—	—	—	—	—	—	X	—	—
511b	X	X	X	X	X	X	X	—	—	X	X	—	X
529	—	X	—	X	—	X	X	X	—	X	—	X	—
X	X	X	—	X	X	X	X	X	—	X	X	—	X
540	—	—	—	—	—	—	X	—	—	—	—	—	—
546	X	X	—	—	—	—	—	—	—	—	X	—	—
563	—	X	—	X	—	—	—	—	—	X	—	X	—
581	—	—	X	—	—	—	—	—	—	X	—	—	—
587	—	—	—	—	—	—	—	—	—	—	—	X	—
593	—	—	—	—	—	—	—	—	—	—	—	X	—
598	—	—	—	—	—	—	—	—	—	X	—	X	—
604	X	X	—	X	X	X	—	—	—	X	—	—	—
612	—	—	—	—	—	X	—	X	—	—	—	—	—
613	—	X	—	—	—	—	—	—	—	—	—	—	—
636	—	—	—	—	—	—	—	—	—	X	—	—	—
681	—	—	—	X	—	—	—	—	—	X	—	X	—
683	—	—	—	—	—	—	—	X	—	—	—	X	—
687	—	—	—	—	—	—	—	—	—	X	X	—	—
703	—	—	—	—	—	—	—	—	—	—	X	—	—
704	—	—	—	—	—	—	—	—	—	—	X	X	—
705	—	X	—	X	—	—	X	—	—	X	—	—	—
719	—	—	—	—	—	—	—	—	—	X	—	—	—
724	—	—	—	X	—	—	—	—	—	—	—	—	—
725	—	—	X	—	—	—	—	—	—	—	—	—	—
731	—	—	—	—	—	—	—	—	—	X	—	—	—
755	—	—	—	—	—	—	—	—	—	X	—	—	—
761	—	X	—	—	—	—	—	—	X	X	X	X	X
766	—	X	—	X	—	—	—	—	—	X	—	X	—
Sp. 48	12	21	8	18	9	13	14	9	7	32	12	18	5

title them to consideration as actual though temporary residents, but as it is, we can only say that in our judgment somewhere between 50 and 75 per cent. of our 166 recorded and counted species were found in numbers sufficient to make them worthy of note as effective agents, for good or evil according to their habits, at some time and in some part of the state. In this very general statement, however, we are making no application of the well established fact that birds in great variety of widely different ordinary habit and habitat may concentrate locally and for a considerable time in a habitat which through some exceptional development offers them unusual inducements.*

On the whole it may be reasonably said that the general outcome of our survey warrants the statement that few kinds of birds are really insignificant everywhere and always and that it is a rational economic policy to preserve and protect all not known to be on the whole positively injurious and to decimate, and exterminate if possible, the few which can be definitely and positively so classed.

CONCERNING THE METHODS OF THE SURVEY

We have frequently remarked upon the discretion to be used in applying the results of our survey, and we have ourselves frequently refrained from drawing seemingly warranted conclusions because of the obvious deficiencies of our data. Unable, of course, to make a complete census of the birds of the state at any time, we have resorted to the method of random sampling; and unless this process is often repeated under every variety of circumstance and condition, the question may always be very properly raised whether the samples chosen adequately represent the whole. We have reason to regret the shortness of the period over which the survey extended and especially the unequal distribution of our data of observation in both time and space, largely due to our limitation to a single field party and the consequent impossibility of making parallel observations in different places at the same time. As the phenomena we were studying were peculiarly subject to seasonal changes, less rapid in summer and winter, but perplexingly so in spring and fall, it was logically necessary that we should have had at least three parties in the field at once, one for each section of the state, all operating on similar programs especially as to times and areas. This being impracticable for us, profitable comparison of our data has been narrowly limited and considerable ingenuity has been called for in the adaptation and assimilation of data of different origin in a way to make them fairly comparable. These differences were attributable to the conditions under which our methods of observation and record were used and not to the methods themselves, which seem to us so well adapted to the end in view that we should not know how

* For an illustrative instance, see "The Regulative Action of Birds upon Insect Oscillations" by S. A. Forbes, Bul. Ill. State Laboratory of Natural History, Vol. I, Art. 6, pp. 1-32, May, 1883.

to improve upon them if we were to continue or repeat the survey. Their special value was in the substitution of precise data, recorded in figures and hence available for accurate comparison and capable of being expanded by subsequent addition, for the vague and variable expressions of degrees of abundance and scarcity now commonly used.

The principal features of method to which we would call attention are:

1. A careful selection of the sample tracts surveyed, with a view to making them as nearly as possible fairly representative of the whole area from which they are chosen.*

2. The accurate recognition and complete enumeration by two observers of all the birds present on long strips or belts of uniform width, one observer recognizing and counting the birds seen on each kind of habitat, and the other recording the distances traveled over each.†

3. The form of field notes written on uniform slips day by day for each trip, the slips being numbered consecutively for convenient reference.

4. The method of tabulation of the observations in a way to make them available for consolidation in various ways and for complete discussion.

5. A species index of the numbered notes such that all the data for each species may be readily assembled.

6. The grouping and tabulation of "residence classes".

7. Use of the tables thus formed in comparing the composition of the bird population in different seasons and especially in different stages of the fall and spring migrations, and the tracing in detail by this means of the successive steps of each migration.

GENERAL SPECIES LIST

The following list of 195 species of which 166 have been statistically treated, comprises all the birds seen and recognized in the entire course of the Illinois survey. The letters in the first three columns of the table indicate a residence classification of the species based primarily on our own observations but taking into account also the published and unpublished observations of others available to us. As our main object is ecological, we have attached relatively little importance to the exceptional occurrence or comparatively insignificant numbers of a species outside its usual range or season of residence, but have classified it only when and where it was found in numbers sufficient to give it some appreciable significance as a feature in the bird life of the time and place.

* We have repeatedly made mention of the fact that our method of enumeration limited us to birds of more or less open country, excluding us from aquatic situations and from dense forests or lofty trees.

† To make sure that practically all the birds were seen by these observers, several trial trips were made with a third person walking between and some distance behind the two; with the result that the number of additional birds thus flushed was altogether negligible.

The letters used have the following meanings:

P. Permanent resident.

W. Winter resident.

S. Summer resident.

M. Migrant.

In the other columns of the table an X indicates the presence of the species on the 90-foot or 150-foot strip completely surveyed, and a J signifies a species noted by the observers but not seen on the surveyed strip.

LIST OF SPECIES RECOGNIZED WITH THEIR RESIDENCE CLASSIFICATION FOR EACH SECTION OF THE STATE, TOGETHER WITH DATA OF THEIR OCCURRENCE IN EACH SECTION AND EACH SEASON OF THE YEAR

	Residence classification			Southern Illinois				Central Illinois				Northern Illinois			
	Southern Illinois	Central Illinois	Northern Illinois	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter
6. Pied-billed Grebe <i>Podilymbus podiceps</i>	S	S	S					J							
51. Herring Gull <i>Larus argentatus</i>	W	W	W					J							
77. Black Tern <i>Hydrochelidon nigra</i> <i>surinamensis</i>	M	M	M					X							
120. Double-crested Cormorant, <i>Phalacrocorax</i> <i>auritus auritus</i>	M	M	M					J	J						
132. Mallard, <i>Anas platyrhynchos</i>	P	P	P					X	J						
140. Blue-winged Teal <i>Querquedula discors</i>	S	S	S					X							
143. Pintail <i>Dafila acuta</i>	M	M	P									X			
144. Wood Duck <i>Aix sponsa</i>	P	P	P						J						
149. Lesser Scaup Duck <i>Marila affinis</i>	W	W	W					J							
172. Canada Goose, <i>Branta</i> <i>canadensis canadensis</i>	W	M	M					X				X			X
190. Bittern, <i>Botaurus</i> <i>lentiginosus</i>	S	S	S						X						
191. Least Bittern <i>Ixobrychus exilis</i>	S	S	S			J									
194. Great Blue Heron <i>Ardea herodias herodias</i>	S	S	S		X				X			X			
201. Green Heron <i>Butorides virescens</i> <i>virescens</i>	S	S	S		X			X	X	X		X	X		
202. Black-crowned Night Heron, <i>Nycticorax nycticorax</i> <i>naevius</i>	S	S	S							J		X			
208. King Rail <i>Rallus elegans</i>	S	S	S					J				X			
212. Virginia Rail <i>Rallus virginianus</i>	S	S	S									X	X		
214. Sora <i>Porzana carolina</i>	S	S	S					X	X			X	X		
219. Florida Gallinule <i>Gallinula galeata</i>	S	S	S					J							
221. Coot <i>Fulica americana</i>	S	S	S					X							
228. Woodcock <i>Philohela minor</i>	S	S	S		X	X									
230. Wilson's Snipe <i>Gallinago delicata</i>	M	M	S	X				X				X			X

LIST OF SPECIES RECOGNIZED WITH THEIR CLASSIFICATION, ETC.—Continued

		Residence classification			Southern Illinois				Central Illinois				Northern Illinois			
		Southern Illinois	Central Illinois	Northern Illinois	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter
231.	Dowitcher <i>Macrorhamphus griseus</i>	M	M	M												X
239.	Pectoral Sandpiper <i>Pisobia maculata</i>	M	M	M					X							X
254.	Greater Yellow-legs <i>Totanus melanoleucus</i>	M	M	M							J					
255.	Yellow-legs <i>Totanus flavipes</i>	M	M	M							J					
256.	Solitary Sandpiper <i>Helodromas solitarius</i>	M	M	M					X	X	X				X	
261.	Upland Plover <i>Bartramia longicauda</i>	S	S	S		X			X	X					X	
262.	Buff-breasted Sandpiper <i>Tryngites subruficollis</i>	M	M	M					X		X					
263.	Spotted Sandpiper <i>Actitis macularia</i>	S	S	S		X			X						X	
272.	Golden Plover <i>Charadrius dominicus</i>	M	M	M					X							
273.	Killdeer <i>Oxyechus vociferus</i>	S	S	S	X	X	X	X	X	X	X		X	X	X	
289.	Bob-white <i>Colinus virginianus</i>	P	P	P	X	X	X	X	X	X	X	X	X	X	X	X
305.	Prairie Chicken <i>Tympanuchus americanus</i>	P	P	P	X	X	X		X	X	X		X	X	X	X
316.	Mourning Dove <i>Zenaidura macroura</i>	P	P	P	X	X	X	X	X	X	X		X	X	X	X
325.	Turkey Vulture <i>Cathartes aura</i>	P	S	S	X	X	X	X	X	X	X		X	X	X	
326.	Black Vulture <i>Catharista urubu</i>	P	—	—		X										
331.	Marsh Hawk <i>Circus hudsonius</i>	P	P	P		X	X		X	X	X	X		X	X	X
332.	Sharp-shinned Hawk <i>Accipiter velox</i>	P	P	P											X	X
333.	Cooper's Hawk <i>Accipiter cooperi</i>	P	P	S			X	X	X					X		
337.	Red-tailed Hawk <i>Buteo borealis borealis</i>	P	P	P	X	X	X	X	X		X		X	X	X	
339.	Red-shouldered Hawk <i>Buteo lineatus lineatus</i>	P	P	P	X	X		X								

LIST OF SPECIES RECOGNIZED WITH THEIR CLASSIFICATION, ETC.—*Continued*

	Residence classification			Southern Illinois				Central Illinois				Northern Illinois			
	Southern Illinois	Central Illinois	Northern Illinois	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter
343. Broad-winged Hawk Buteo platypterus	P	S	S		X										
347a. Rough-legged Hawk Archibuteo lagopus sanctijohannis	W	W	W						X	X		X			X
349. Golden Eagle Aquila chrysaetos	P	P	P				X								
352. Bald Eagle Haliaetus leucocephalus leucocephalus	P	P	P				J								
357. Pigeon Hawk Falco columbarius columbarius	M	M	M		X				X						
360. Sparrow Hawk Falco sparverius sparverius	P	S	S	X	X	X	X	X	X	X	X	X	X	X	X
364. Osprey Pandion haliaetus carolinensis	S	S	S						J						
366. Long-eared Owl Asio wilsonianus	P	P	P				X			X					X
367. Short-eared Owl Asio flammeus	P	P	P					X							
368. Barred Owl Strix varia varia	P	P	P	X											
372. Saw-whet Owl Cryptoglaux acadica acadica	P	P	P								J				
373. Screech Owl Otus asio naevius	P	P	P								J				
387. Yellow-billed Cuckoo Coccyzus americanus americanus	S	S	S		X				X	X			X	X	
388. Black-billed Cuckoo Coccyzus erythrophthalmus	S	S	S		X			X					X		
390. Belted Kingfisher Ceryle alcyon	P	S	S	X	X			X	X	X			X	X	
393. Hairy Woodpecker Dryobates villosus villosus	P	P	P		X		X	X		X	X	X	X	X	X
394c. Downy Woodpecker Dryobates pubescens medianus	P	P	P	X	X	X	X	X	X	X	X	X	X	X	X
402. Yellow-bellied Sapsucker Sphyrapicus varius varius	M	M	M	X				X	X						

LIST OF SPECIES RECOGNIZED WITH THEIR CLASSIFICATION, ETC.—Continued

[illegible]

LIST OF SPECIES RECOGNIZED WITH THEIR CLASSIFICATION, ETC.—*Continued*

	Residence classification			Southern Illinois				Central Illinois				Northern Illinois			
	Southern Illinois	Central Illinois	Northern Illinois	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter
477. Blue Jay Cyanocitta cristata cristata	P	P	P	X	X	X	X	X	X	X	X	X	X	X	X
488. Crow Corvus brachyrhyn- chos brachyrhynchos	P	P	P	X	X	X	X	X	X	X	X	X	X	X	X
494. Bobolink Dolichonyx oryzivorus	M	M	S		X			X	X	X			X	X	
495. Cowbird Molothrus ater ater	S	S	S	X	X	X		X	X	X			X	X	X
498. Red-winged Blackbird Agelaius phoeniceus phoeniceus	S	S	S	X	X	X		X	X	X			X	X	X
501. Meadowlark Sturnella magna magna	P	S	S	X	X	X	X	X	X	X	X	X	X	X	X
506. Orchard Oriole Icterus spurius	S	S	S		X			X	X					X	
507. Baltimore Oriole Icterus galbula	S	S	S		X			X	X	X				X	
509. Rusty Blackbird Euphagus carolinus	M	M	M	X		X		X		X		X			
510. Brewer's Blackbird Euphagus cyanoceph- alus	M	M	M											X	
511b. Bronzed Grackle Quiscalus quiscula aeneus	S	S	S	X	X	X		X	X	X		X	X	X	
517. Purple Finch Carpodacus purpureus purpureus	W	W	P				X			X					
528. Redpoll Acanthis linaria linaria	W	W	W												X
529. Goldfinch Astragalinus tristis tristis	P	P	P	X	X	X	X	X	X	X	X	X	X	X	X
X. English Sparrow Passer domesticus	P	P	P	X	X	X	X	X	X	X	X	X	X	X	X
533. Pine Siskin Spinus pinus	W	W	W			X									
534. Snow Bunting Plectrophenax nivalis nivalis	W	W	W								X				
536. Lapland Longspur Calcarius lapponicus lapponicus	W	W	W					X			X	X			X

LIST OF SPECIES RECOGNIZED WITH THEIR CLASSIFICATION, ETC.—Continued

	Residence classification			Southern Illinois				Central Illinois				Northern Illinois			
	Southern Illinois	Central Illinois	Northern Illinois	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter
537. Smith's Longspur <i>Calcarius pictus</i>	M	M	M					X							
540. Vesper Sparrow <i>Pooecetes gramineus</i>	M	S	S	X	X	X		X	X	X		X	X	X	
542a. Savannah Sparrow <i>Passerculus sand- wichensis savanna</i>	M	M	S	X		X		X		X			X	X	
546. Grasshopper Sparrow <i>Ammodramus savan- narum australis</i>	P	S	S	X	X	X		X	X	X			X	X	
547. Henslow's Sparrow <i>Passerherbulus hen- slowi henslowi</i>	S	S	S			X			X	X					
548. Leconte's Sparrow <i>Passerherbulus lecontei</i>	M	M	M							X					
549i. Nelson's Sparrow <i>Passerherbulus nelsoni nelsoni</i>	M	M	M							X					
552. Lark Sparrow <i>Chondestes grammacus grammacus</i>	S	S	S		X			X	X				X		
554. White-crowned Sparrow <i>Zonotrichia leucophrys leucophrys</i>	W	M	M	X		X		X		X					
558. White-throated Sparrow <i>Zonotrichia albicollis</i>	W	M	M	X		X	X	X		X					
559. Tree Sparrow <i>Spizella monticola monticola</i>	W	W	W	X		X	X	X		X	X	X			X
560. Chipping Sparrow <i>Spizella passerina passerina</i>	S	S	S	X	X	X		X	X	X			X	X	
563. Field Sparrow <i>Spizella pusilla pusilla</i>	S	S	S	X	X	X	X	X	X	X			X	X	
567. Slate-colored Junco <i>Junco hyemalis hyemalis</i>	W	W	W	X		X	X	X		X	X	X			X
575a. Bachman's Sparrow <i>Peucaea aestivalis bachmani</i>	S	S	S	X	X			X							
581. Song Sparrow <i>Melospiza melodia melodia</i>	P	P	S	X		X	X	X	X	X	X	X	X	X	X
583. Lincoln's Sparrow <i>Melospiza lincolni lincolni</i>	S	S	S			X				X					

LIST OF SPECIES RECOGNIZED WITH THEIR CLASSIFICATION, ETC.—Continued

	Residence classification			Southern Illinois				Central Illinois				Northern Illinois			
	Southern Illinois	Central Illinois	Northern Illinois	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter
584. Swamp Sparrow Melospiza georgiana	W	M	S		X	X	X	X		X	X		X	X	X
585. Fox Sparrow Passerella iliaca iliaca	W	M	M			X	X	X		X					
587. Towhee Pipilo erythrophthalmus erythrophthalmus	P	S	S	X	X	X	X	X	X	X			X		
593. Cardinal Cardinalis cardinalis cardinalis	P	P	P	X	X	X	X	X	X	X	X		X		
595. Rose-breasted Grosbeak Zamelodia ludoviciana	M	S	S						X				X		
598. Indigo Bunting Passerina cyanea	S	S	S		X			X	X	X			X	X	
604. Dickcissel Spiza americana	S	S	S		X			X	X	X			X	X	
608. Scarlet Tanager Piranga olivacea	S	S	S		X			X							
610. Summer Tanager Piranga rubra rubra	S	S	S		X										
611. Purple Martin Progne subis subis	S	S	S		X			X		X			X	X	
612. Cliff Swallow Petrochelidon lunifrons lunifrons	S	S	S		X			X	X	X			X	X	
613. Barn Swallow Hirundo erythrogastra	S	S	S	X	X			X	X	X			X	X	
614. Tree Swallow Iridoprocne bicolor	S	S	S					X		X					
616. Bank Swallow Riparia riparia	S	S	S		X			X	X	X			X		
617. Rough-winged Swallow Stelgidopteryx serripennis	S	S	S					J							
618. Bohemian Waxwing Bombycilla garrula	W	W	P										X		
619. Cedar Waxwing Bombycilla cedrorum	P	P	P						X						
622e. Migrant Shrike Lanius ludovicianus migrans	P	P	S	X	X	X	X	X	X	X	X	X	X	X	X
624. Red-eyed Vireo Vireosylva olivacea	S	S	S		X			X	X	X			X		
626. Philadelphia Vireo Vireosylva philadel- phica	M	M	M						X						
627. Warbling Vireo Vireosylva gilva gilva	S	S	S		X			X					X	X	

LIST OF SPECIES RECOGNIZED WITH THEIR CLASSIFICATION, ETC.—*Continued*

	Residence classification.			Southern Illinois				Central Illinois				Northern Illinois			
	Southern Illinois	Central Illinois	Northern Illinois	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter
628. Yellow-throated Vireo															
<i>Lanivireo flavifrons</i>	S	S	S							J					
629. Blue-headed Vireo															
<i>Lanivireo solitarius</i>	M	M	M							X					
631. White-eyed Vireo															
<i>Vireo griseus griseus</i>	S	S	S	X											
633. Bell's Vireo															
<i>Vireo belli belli</i>	S	S	S	J											
636. Black and White															
Warbler															
<i>Mniotilta varia</i>	S	S	S					X	X	X		X	X		
637. Prothonotary Warbler															
<i>Protonotaria citrea</i>	S	S	S	J				J							
638. Swainson's Warbler															
<i>Helinaia swainsoni</i>	S	S	S	J											
639. Worm-eating Warbler															
<i>Helmitheros</i>															
<i>vermivorus</i>	S	S	S					X							
641. Blue-winged Warbler															
<i>Vermivora pinus</i>	S	S	S					J		J					
645. Nashville Warbler															
<i>Vermivora rubricapilla</i>	M	M	M							X		X	X		
646. Orange-crowned															
Warbler															
<i>Vermivora celata</i>															
<i>celata</i>	M	M	M							X					
647. Tennessee Warbler															
<i>Vermivora peregrina</i>	M	M	M							X		X	X		
648a. Northern Parula Warbler															
<i>Compsothlypis ameri-</i>															
<i>cana usneae</i>	S	S	S					X							
650. Cape May Warbler															
<i>Dendroica tigrina</i>	M	M	M									X	X		
652. Yellow Warbler															
<i>Dendroica aestiva</i>															
<i>aestiva</i>	S	S	S	X								X			
654. Black-throated Blue															
Warbler															
<i>Dendroica caerulescens</i>															
<i>caerulescens</i>	M	M	M									X	X		
655. Myrtle Warbler															
<i>Dendroica coronata</i>	M	M	M		X			X		X					
657. Magnolia Warbler															
<i>Dendroica magnolia</i>	M	M	M					X		X		X	X		
659. Chestnut-sided Warbler															
<i>Dendroica pensyl-</i>															
<i>vanica</i>	M	M	S					X	X			X	X		

LIST OF SPECIES RECOGNIZED WITH THEIR CLASSIFICATION, ETC.—*Continued*

		Residence classification			Southern Illinois				Central Illinois				Northern Illinois			
		Southern Illinois	Central Illinois	Northern Illinois	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter
661.	Black-poll Warbler <i>Dendroica striata</i>	M	M	M											X	X
662.	Blackburnian Warbler <i>Dendroica fusca</i>	M	M	M							J					
663a.	Sycamore Warbler <i>Dendroica dominica</i> <i>albilora</i>	S	S	S	J											
667.	Black-throated Green Warbler <i>Dendroica virens</i>	M	M	M							X			X	X	
671.	Pine Warbler <i>Dendroica vigorsi</i>	P	S	S		X										
672.	Palm Warbler <i>Dendroica palmarum</i> <i>palmarum</i>	M	M	M						X	X			X	X	
674.	Oven-bird <i>Seiurus aurocapillus</i>	S	S	S						J						
675a.	Grinnell's Water- Thrush <i>Seiurus noveboracensis</i> <i>notabilis</i>	M	M	M						X				X	X	
676.	Louisiana Water- Thrush <i>Seiurus motacilla</i>	S	S	S						J						
677.	Kentucky Warbler <i>Oporornis formosus</i>	S	S	S						J						
679.	Mourning Warbler <i>Oporornis philadelphia</i>	M	M	M						J						
681d.	Maryland Yellow-throat <i>Geothlypis trichas</i> <i>trichas</i>	S	S	S		X				X	X	X		X		
683.	Yellow-breasted Chat <i>Icteria virens virens</i>	S	S	S		X				X						
684.	Hooded Warbler <i>Wilsonia citrina</i>	S	S	S			J									
686.	Canada Warbler <i>Wilsonia canadensis</i>	M	M	M						J						
687.	Redstart <i>Setophaga ruticilla</i>	S	S	S						X	X	X		X	X	
697.	Pipit <i>Anthus rubescens</i>	M	M	M	X	X				X	X					X
703.	Mockingbird <i>Mimus polyglottos</i> <i>polyglottos</i>	P	S	S		X	X	X		X	X	X		X		
704.	Catbird <i>Dumetella carolinensis</i>	S	S	S		X				X	X	X		X	X	
705.	Brown Thrasher <i>Toxostoma rufum</i>	S	S	S	X	X				X	X	X		X	X	

LIST OF SPECIES RECOGNIZED WITH THEIR CLASSIFICATION, ETC.—Continued

	Residence classification			Southern Illinois				Central Illinois				Northern Illinois			
	Southern Illinois	Central Illinois	Northern Illinois	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter
718. Carolina Wren <i>Thryothorus ludovicianus ludovicianus</i>	P	S	S		X	X	X								
719. Bewick's Wren <i>Thryomanes bewicki bewicki</i>	S	S	S		X	X		X		X					
721a. Western House Wren <i>Troglodytes aedon parkmani</i>	S	S	S		X			X	X	X				X	
722. Winter Wren <i>Nannius hiemalis hiemalis</i>	W	W	M			X									
724. Short-billed Marsh Wren <i>Cistothorus stellaris</i>	W	S	S		X			X		X			X	X	
725. Long-billed Marsh Wren <i>Telmatodytes palustris palustris</i>	S	S	S										X	X	
726. Brown Creeper <i>Certhia familiaris americana</i>	W	M	M				X	X		X					X
727. White-breasted Nuthatch <i>Sitta carolinensis carolinensis</i>	P	P	P		X	X	X	X	X	X	X	X		X	X
728. Red-breasted Nuthatch <i>Sitta canadensis</i>	M	M	M						X						
731. Tufted Titmouse <i>Baeolophus bicolor</i>	P	P	P		X	X	X	X		X	X				
735. Chickadee <i>Penthestes atricapillus atricapillus</i>	P	P	P		X			X		X	X	X	X	X	X
736. Carolina Chickadee <i>Penthestes carolinensis carolinensis</i>	P	P			X	X	X	X	X	X	X				
748. Golden-crowned Kinglet <i>Regulus satrapa satrapa</i>	W	W	M			X		X		X					
749. Ruby-crowned Kinglet <i>Regulus calendula calendula</i>	M	M	M						X		X				
751. Blue-gray Gnatcatcher <i>Poliophtila caerulea caerulea</i>	S	S	S							X					
755. Wood Thrush <i>Hylocichla mustelina</i>	S	S	S		X					X					
756. Veery <i>Hylocichla fuscescens fuscescens</i>	M	M	S					X							

LIST OF SPECIES RECOGNIZED WITH THEIR CLASSIFICATION, ETC.—*Concluded*

	Residence classification			Southern Illinois				Central Illinois				Northern Illinois			
	Southern Illinois	Central Illinois	Northern Illinois	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter
757. Gray-cheeked Thrush Hylocichla aliciae aliciae	M	M	M					J							
758a. Olive-backed Thrush Hylocichla ustulata swainsoni	M	M	M					X		X					
759b. Hermit Thrush Hylocichla guttata pallasii	W	M	M					X							
761. Robin Planesticus migratorius migratorius	P	S	S	X	X	X	X	X	X	X		X	X	X	
766. Bluebird Sialia sialis sialis	P	S	S	X	X	X	X	X	X	X		X	X	X	X

EXAMPLES OF FIELD NOTES, INDEX CARDS, AND PRINCIPAL TABLES
MADE UP FROM THEM.

FIELD NOTES

The following copies of four note slips will sufficiently illustrate the method of recording the field data. The number following the date at the head of the slip, is the serial number of the slip itself. The figures opposite the names of habitats ("pasture", "stubble", "corn stalks", etc.) show the number of paces taken in crossing a field, the observer counting the birds on a 50-yard strip except where the habitat name is followed by the expression "30 yards". The number and kinds of birds seen in each field on the 50-yard or 30-yard strip are shown by the figures under the habitat name, the first the number of birds and the second the A. O. U. number for the species name.* (8-289 means 8 bob-whites or quails seen in crossing a pasture 310 paces wide.)

Feb. 14, 1907	507	(Broken trees)	
Brownfield, Illinois		13-567	
Fair, cold, wind N. E.		Weeds	34
Ground not frozen.	8:00 A. M.	30 yd.	
Pasture	310		
8-289		Feb. 14, 1907	508
Stubble	80	C. Stalks	270
1-567		8-501	
Pasture	92	24-567	

* The symbol X is used for the English sparrow.

3-766		Pasture	332
1-4746		Timothy	82
Timothy	42	3-501	
(Grasshopper, a butterfly, and small gnats found)		Plowed Gd.	294
Shrubby	312	C. Stalks	154
30 yd.		Beans (garden)	88
2-559		Shrubby	25
7-567		30 yd.	
1-517		2-766	
19-289		Pasture (Weeds)	64
Timber	242	C. Stalks	75
30 yd.		C. Stubble (corn)	97
3-567		Wild grass	47
1-718		Wheat	134
1-727		Stubble	117
2-731		Barnyard	152
2-409		2-X	
Pasture	394	Feb. 14, 1907	510
(Some shrubby)		Waste Gd.	372
Stubble	570	Timber	989
1-581		30 yd.	
C. Stalks	100	2-563	
10-501		18-567	
Feb. 14, 1907	509	1-731	
Pasture	56	1-593	
C. Stalks	116	Wheat	218
Pasture	120	C. Stubble	47
Stubble	220	Pasture	60
Waste Ld.	214	Shrubby	555
Road—12:10		30 yd.	
Timber	288	1-394c	
30 yd.		8-517*	
1-559		Wheat	104
1-567		Timber	418
C. stalks	37	30 yd.	
Weeds	306	2-736	
(A few apple trees)		Weeds	156
30 yd.		Pasture	274
Orchard	80	(Horses)	
Stubble	294	Waste Gd.	103
Orchard	94	Golconda, Ill., 2:30 P. M.	
(Yg. wheat)			
Road	11:00 A. M.		

* 3 males, 5 females.

INDEX CARDS

The black-face figures on the following cards indicate the species names (305, prairie chicken, and 111, kingbird) and the other figures refer to the serial numbers of the field note-slips on which the species is mentioned. The index cards are filed in the order of their species numbers.

305-	48,	77,	89,	104,	121.
217,	281,	285,	291,	309,	316,
324,	328,	330,	336,	544,	570,
588,	589,	592,	601,	614,	616,

617, 631, 642, 648, 650, 651,
 687, 710, 735, 739, 806, 819,
 825, 831, 833, 834, 848, 849,
 1131, 1162, 1185, 1198, 1204, 1220,
 1295, 1343, 1488, 1490, 1555, 1570,
 1580, 1582, 1798, 1809, 1813, 1856,
 1928, 2039

444- 1440, 1443, 1447, 1448, 1454,
 1459, 1460, 1462, 1464, 1467, 1471,
 1472, 1475, 1481, 1493, 1497, 1513,
 1514, 1520, 1530, 1545, 1554, 1565,
 1569, 1574, 1580, 1583, 1585, 1590,
 1591, 1597, 1601, 1608, 1612, 1614,
 1624, 1625, 1626, 1628, 1634, 1636,
 1640, 1641, 1642, 1643, 1645, 1648,
 1649, 1667, 1671, 1675, 1677, 1679,
 1680, 1697, 1701, 1702, 1703, 1704,
 1714, 1719, 1734, 1742, 1747, 1751,
 1771, 1775, 1781, 1785, 1802, 1812,
 1818, 1819, 1820, 1824, 1827, 1828,
 1829, 1835, 1842, 1843, 1844, 1845,
 1853, 1859, 1862, 1868, 1872, 1876,
 1884, 1888, 1890, 1895, 1896, 1904,
 1909, 1918, 1932, 1933, 1934, 1944,
 1947, 1960, 1961, 1964, 1967, 1980,
 1990, 1994, 2000, 2016, 2027.

TABLE III

NORTHERN ILLINOIS, SEPTEMBER 6-15, 1909

Most abundant species, amounting to 85% of whole number identified; with ratios of each number to total number of birds.

Species	Number of each	Ratio to total number of birds Per cent.
X	1369	34.0
511b	1321	33.0
494	428	10.7
761	105	2.6
498	100	2.5
412	84	2.1
Total	3407	84.9

Whole number = 4017
85% = 3414

TABLE IV

NORTHERN ILLINOIS, SEPTEMBER 6-15, 1909

Showing distance traveled over each crop, acreage of each crop, and ratio of acreage of each crop to total acreage covered.

Crops	Distance traveled in miles	Acreage covered	Ratio to total acreage Per cent.
Corn	28.23	513.22	29.3
Pasture	23.76	431.96	24.6
Meadow	12.61	229.25	13.1
Stubble	19.68	357.78	20.4
Orchard	1.29	9.38	0.5
Timber	0.99	7.18	0.4
Plowed ground	2.34	42.54	2.4
Yards	2.75	50.00	2.8
Gardens	2.90	52.72	3.0
Waste and fallow	1.64	29.82	1.7
Swamp	0.75	13.64	0.8
Wheat	0.22	4.00	0.2
Oats	0.80	14.54	0.8
Total	97.96	1756.03	100.

TABLE V

NORTHERN ILLINOIS, SEPTEMBER 6-15, 1909

Showing the number of "All Birds" in each crop, per cent. in each crop, birds per acre, and birds per square mile.

Crops	Number of Birds	Ratio to total No. of birds Per cent.	Birds per Acre	Birds per Square Mile
Corn	1551	38.6	3.02	1937
Pasture	681	17.0	1.58	1010
Meadow	321	8.0	1.40	895
Stubble	254	6.3	0.71	455
Orchard	171	4.2	18.23	11712
Timber	20	0.5	2.78	1786
Plowed ground	28	0.7	0.65	420
Yards	891	22.2	17.82	11409
Gardens	63	1.6	1.19	765
Waste and fallow	19	0.5	0.64	408
Swamp	14	0.3	1.03	657
Wheat	4	0.1	1.00	640
Total	4017	100.	2.27	1458

TABLE VI (a)

NORTHERN ILLINOIS, WINTER, NOVEMBER 23-30, 1906 AND JANUARY 2-16, 1907

Showing the number of each principal species that was observed in each of the principal crops.

Species	Corn	Stubble	Pasture	Meadow	Plowed	Woods	Shrubby and gardens	Fallow and waste	All crops
X	13	1	31	1	4				50
305	19	9	4						32
394c	3		2			6	2	1	15
474b*		15	11	3	8				75
477	3		7			1	12	2	25
488	30	57	28	19	2	15		33	207
529	58	4	116	1					179
536†	65	160	1	158	7				675
559	18	6	43	3		4		62	137
735	5		16			6	8	6	43
All birds	225	258	272	193	30	41	25	127	1520

* 38 out of 75 of the 474b were found in wheat fields.

† 284 out of 675 of the 536 were found in wheat fields.

TABLE VI (b)

BELOIT, WISCONSIN, TO EARLVILLE, ILLINOIS, NOVEMBER 23-30, 1906

Showing number of principal birds in principal crops per square mile.

Species	Corn	Stubble	Wheat	Plowed ground	Pasture	Meadow crops
X	27.1			16.5	3.4	6.0
305	39.7	57.3			13.6	
474	6.3				27.2	6.0
474b		12.7		8.3	13.6	18.1
488	41.7	38.2		8.3	23.8	78.4
529	6.3				68.1	
536	135.7		6035.0	29.0	3.4	952.4
559	25.0				47.7	12.1

TABLE VI (c)

NORTHERN ILLINOIS, WINTER, NOVEMBER 23-30, 1906, AND JANUARY 2-16, 1907

Showing the per cent. of each principal species that was observed in each of the principal crops.

Species	Corn %	Stubble %	Pasture %	Meadow %	Plowed %	Woods %	Shrub- bery and Gardens %	Fallow and Waste %
X	26.0	2.0	62.0	2.0	8.0			
305	59.4	28.1	12.5					
394c	20.0		13.3			40.0	13.3	6.7
474b		20.0	14.7	4.0	10.7			
477	12.0		28.0			4.0	48.0	8.0
488	14.5	27.5	13.5	9.2	1.0	7.2		15.9
529	32.4	2.2	64.8	0.6				
536	9.6	23.7	0.1	23.4	1.0			
559	13.1	4.4	31.4	2.2		2.9		45.3
735	11.6		37.2			14.0	18.6	14.0

INDEX

A

Abramis crysoleucas, 385 (opposite).
Acanthis linaria linaria, 442.
Accipiter cooperi, 439.
 velox, 439.
Acer saccharinum, 307.
 saccharum, 307.
Actitis macularia, 439.
Aedes canadensis, 31.
 sollicitans, 30, 31.
Agelaius phoeniceus phoeniceus, 442.
Agrostis palustris, 138.
Aix sponsa, 438.
Albugo, 136, 165.
Alternaria, 78, 79, 105, 109, 124, 137,
 167, 170.
 Amber cane, 138.
Ambloplites rupestris, 384, 385 (op-
 posite).
Amebae, 79, 124.
Ameiurus melas, 386.
Ammodramus savannarum australis,
 443.
Amnicola emarginata, 37, 50, 55, 60.
 spp., 36, 55.
Amnicolidae, 37, 38, 39, 46, 47, 48, 50,
 53, 55, 58, 60, 62, 63, 69, 73.
Amphipoda, 36, 71.
Anacharis canadensis, 12.
Anas platyrhynchos, 438.
Ancylidae, 37, 50, 55.
Ancylus sp., 36, 37, 50, 55.
Anopheles, 23.
 crucians, 30, 31.
 guttulatus, 30, 31, 32.
 punctipennis, 31, 32.
Anthus rubescens, 446.
Antrostomus vociferus vociferus, 441.
 Apple orchards, 291.
 rust, 307.
Aquila chrysaetos, 440.

Archibuteo lagopus sanctijohannis,
 440.
Archilochus colubris, 441.
Ardea herodias herodias, 438.
Ascochyta, 160.
 chrysanthemi, 166.
Asellus, 57.
 aquaticus, 52.
Ash, 293, 313, 314, 315, 316, 334, 346.
 Gray, 307.
 Green, 307.
 White, 307.
 Ashes, 336.
Asio flammeus, 440.
 wilsonianus, 440.
Aspergillus, 163.
Asteromeyenia, 10, 13.
 plumosa, 17.
 radiospiculata, 13, 14, 17.
Astragalinus tristis tristis, 442.

B

Bacillus carotovorus, 133.
 coli, 158.
 omnivorus, 133.
Bacteria, 138, 139, 158.
Bactridium, 107.
Baeolophus bicolor, 47.
Barley, 90, 91, 125, 126, 137, 138, 139,
 153, 170, 181, 182.
Bartramia longicauda, 439.
Bass, 386, 387.
 Large-mouthed, 382.
 Rock, 382, 386.
Basswood, 309, 314.
Beans, 138.
Beech, 293, 297, 303, 304, 313, 314, 315,
 316, 332, 336, 337, 339, 365.
 Blue 311, 312.
 -*maple type of forest*, 298, 343.
Berries, 291.

- Birch, 303, 339.
 Birches, 336.
 Birds, 1-8, 187-218, 397-453.
 Bittern, 438.
 Least, 438.
 Blackbird, Brewer's, 442.
 Crow, 190, 191, 192, 193, 200, 202, 205, 206, 207, 209, 211, 212, 214, 216, 421, 431. See also *Bronzed Grackle*.
 Red-Winged, 190, 191, 193, 194, 195, 196, 197, 200, 201, 202, 203, 206, 207, 208, 212, 213, 214, 217, 418, 419, 427, 432, 442.
 Rusty, 416, 418, 419, 420, 427, 442.
 Blackbirds, 430, 431.
 Bluebird, 194, 197, 201, 208, 209, 213, 214, 217, 400, 408, 409, 410, 411, 412, 413, 414, 416, 418, 421, 422, 428, 429, 433, 448.
 Bluegills, 383, 386.
 Blue-grass, 324, 347.
 Blue Jay, 4, 6, 7, 194, 197, 201, 208, 209, 210, 211, 213, 214, 217, 400, 411, 412, 413, 414, 422, 427, 428, 442.
 stem, 347.
 Bobolink, 190, 191, 192, 193, 196, 197, 198, 201, 202, 203, 207, 212, 213, 214, 215, 217, 432, 442.
 Bob-white or quail, 3, 6, 7, 190, 191, 193, 194, 197, 198, 201, 203, 206, 207, 208, 209, 210, 211, 212, 213, 214, 217, 400, 407, 408, 409, 410, 411, 412, 413, 414, 422, 427, 428, 429, 431, 432, 439.
 Bombycilla cedrorum, 444.
 garrula, 444.
 Boston Fern, 158.
 Botaurus lentiginosus, 438.
 Botrytis, 107, 109, 132, 162, 163, 165.
 cinerea, 133, 161.
 Branta canadensis canadensis, 438.
 Bronzed Grackle, 4, 191, 193, 194, 195, 196, 197, 198, 200, 201, 202, 203, 206, 207, 208, 210, 211, 213, 217, 416, 418, 419, 420, 423, 427, 428, *Bronzed Grackle—Continued.*
 429, 431, 432, 442. See also *Crow Blackbird*.
 Bryozoa, 36, 45, 52, 54, 57, 67, 71.
 Bullhead, 386, 388.
 Black, 388.
 Bunting, Indigo, 194, 197, 208, 210, 211, 214, 215, 217, 433, 444.
 Snow, 442.
 Buteo borealis borealis, 439.
 lineatus lineatus, 439.
 platypterus, 440.
 Butorides virescens virescens, 438.
 Butternut, 313, 315, 336.
- C**
- Caddis larva, Sand-case building, 45, 54, 67.
 Caenis, 52.
 Calcarius lapponicus lapponicus, 442.
 pictus, 443.
 Campeloma subsolidum, 36, 37, 50, 55, 60.
 Canada Goose, 398, 419, 420, 438.
 Cardinal, 7, 208, 209, 210, 211, 214, 215, 217, 399, 400, 407, 408, 410, 412, 413, 414, 422, 427, 433, 444.
 Cardinalis cardinalis cardinalis, 444.
 Carp, 386, 387.
 Carpinus caroliniana, 312.
 Carpodacus purpureus purpureus, 442.
 Carterius latitenta, 13, 14.
 tenosperma, 17.
 tubisperma, 12, 13, 15, 16, 17.
 Carya porcina, 305.
 Catalpa, 336.
 Catbird, 209, 210, 211, 214, 215, 217, 446.
 Catharista urubu, 439.
 Cathartes aura septentrionalis, 439.
 Cedar apples, 307.
 Cedar, Red, 302, 307, 312.
 Cedars, 336.
 Celtis mississippiensis, 310.
 occidentalis, 310.
 Centurus carolinus, 441.
 Ceratophyllum, 46, 72.
 Cercis canadensis, 311.

- Certhia familiaris americana*, 447.
Ceryle alcyon, 440.
Chaetochloa, 183.
 italica, 138.
 italica germanica, 138.
Chaetomium, 109.
Chaetura pelagica, 441.
Chara, 13.
Charadrius dominicus dominicus, 439.
 Cherry, 336, 346.
 Wild Black, 309.
 Chestnut, 336, 339.
 Chickadee, 400, 410, 412, 413, 414, 447.
 Carolina, 7, 211, 400, 412, 413, 428, 433, 447.
Chironomidae, 33, 36, 40-44, 45, 46, 47, 48, 49, 51, 52, 53, 56, 57, 58, 64, 65, 69, 71, 72-73. See also Midges.
Chironomus crassicaudatus, 40, 42.
 decorus, 40, 42, 51, 56, 64, 65.
 digitatus, 56.
 dux, 56.
 ferrugineovittatus, 51, 56, 64, 65, 72.
 frequens, 40, 42.
 lobiferus, 41, 42, 51, 56, 65, 72.
 maturus, 40, 42.
 modestus, 51, 65.
 nigricans, 42.
 plumosus, 40, 42, 51, 64.
 plumosus, var., 40, 42.
 sp., 51, 56, 64, 65.
 tentans, 41, 42, 51, 56, 65.
 viridicollis, 41, 42, 51.
Chondestes grammacus grammacus, 443.
Chordeiles virginianus virginianus, 441.
Chrysanthemum, 158.
 Chub-suckers, 387, 388.
Circus hudsonius, 439.
Cistothorus stellaris, 447.
Claviceps, 165.
 Clover, Japanese, 347.
 Red, 324.
 Sweet, 324.
Coccyzus americanus americanus, 440.
 erythrophthalmus, 440.
 Codling-moth investigations, 1915, 1916, 1917, 219-289.
Colaptes auratus luteus, 441.
Coleus, 158.
Colinus virginianus virginianus, 439.
Colletotrichum, 133, 134, 161, 165, 166, 167.
Compsothlypis americana usneae, 445.
Coniothyrium, 163.
 pirinum, 160, 166.
 Coot, 438.
Coregonus clupeiformis, 384.
Corixidae, 35, 52, 57, 71.
 Cormorant, Double-crested, 438.
 Corn, 90, 125, 126, 137, 138, 170, 183, 185, 291.
Cornus florida, 311.
Corvus brachyrhynchos brachyrhynchos, 442.
 Cottonwood, 293, 294, 299, 302, 308, 311, 331, 333, 334, 337, 339, 340, 350, 366.
 Black or Swamp, 310.
 Common, 311.
 Cowbird, 190, 191, 192, 193, 194, 195, 197, 200, 201, 203, 205, 206, 207, 208, 210, 211, 214, 217, 419, 421, 422, 423, 427, 428, 432, 442.
 Crappie, 386.
 Crayfishes, 392.
 Creeper, Brown, 447.
Cricotopus sp., 42, 56.
 trifasciatus, 51, 56.
 Crow, 190, 191, 193, 195, 196, 197, 198, 201, 203, 206, 208, 210, 211, 213, 214, 217, 400, 401, 402, 407, 408, 409, 410, 411, 412, 414, 416, 418, 421, 422, 427, 428, 429, 430, 431, 442.
 Crustacea, 45, 46, 47, 48, 49, 53, 58, 67, 69, 73.
Cryptoglaux acadica acadica, 440.
 Cuckoo, Black-billed, 440.
 Yellow-billed, 440.
 Cucumber-tree, 297, 303, 308.
 Cucumbers, 291.

- Culex apicalis*, 31.
 degustator, 30, 31.
 pipiens, 31.
 restuans, 31.
 salinarius, 31.
 saxatilis, 31.
 territans, 31.
Culiseta inornata, 31.
 Cutworms, 201.
Cyanocitta cristata cristata, 442.
 Cypress, 293, 299, 300, 302, 305, 306,
 311, 317, 327, 336, 357.
 Bald, 306.

D

- Dafila acuta*, 438.
Dematium, 109.
Dendroica aestiva aestiva, 445.
 caerulescens caerulescens, 445.
 coronata, 445:
 dominica albilora, 446.
 fusca, 446.
 magnolia, 445.
 palmarum, *palmarum*, 446.
 pennsylvanica, 445.
 striata, 446.
 tigrina, 445.
 vigorsii, 446.
 virens, 446.
 Diatomaceae, 13.
Dicaeoma poculiformis, 165.
 Dickcissel, 192, 193, 194, 195, 196, 197,
 198, 201, 202, 203, 204, 205, 207,
 208, 212, 213, 214, 215, 217, 433,
 444.
Diffugia, 162.
Diobotryon, 165.
Diospyros virginiana, 311.
 Dogwood, 311, 346.
Dolichonyx oryzivorus, 442.
Dosilia palmeri, 17.
 Dove, Mourning, 3, 6, 7, 190, 191, 193,
 194, 195, 196, 197, 198, 200, 201,
 202, 203, 204, 205, 206, 207, 208,
 209, 210, 211, 213, 214, 216, 217,
 400, 407, 408, 416, 421, 422, 424,
 427, 428, 432, 439.

- Dowitcher*, 439.
Dragon-fly nymph, 379, 385.
Dryobates pubescens medianus, 440.
 villosus villosus, 440.
 Duck, Lesser Scaup, 438.
 Pintail, 419, 438.
 Wood, 438.
 Duckweed, 388.
Dumetella carolinensis, 446.

E

- Eagle, Bald, 440.
 Golden, 440.
 Earthworms, 207.
 Elm, 293, 299, 313, 214, 315, 316, 331,
 333, 344, 345, 346.
 American or White, 310.
 Slippery or Red, 310, 316.
 Winged, 310.
 Elms, 336.
Empidonax flaviventris, 441.
 minimus, 441.
 traillii alnorum, 441.
 virescens, 441.
 Entomostraca, 392.
 Ephemeridae, 36, 52, 57, 71.
Ephydatia baileyi, 17.
 crateriformis, 14, 15, 16, 17.
 everetti, 17.
 fluvialis, 11, 12, 13, 14, 15, 16, 17.
 japonica, 11.
 mexicana, 17.
 japonica, 11.
 millsii, 17.
 mulleri, 11, 12, 13, 15, 16, 17.
 japonica, 11.
 robusta, 17.
 subdivisa, 17.
 subtilis, 17.
Epicoccus, 78, 109, 124.
Euphagus carolinus, 442.
 cynocephalus, 442.

F

- Fagus grandifolia*, 303.
Falco columbarius columbarius, 440.
 sparverius sparverius, 440.

Helminthosporium—*Continued*.

- teres, 98, 105, 109, 111, 117, 119, 123,
 125, 134, 139, 153, 167, 168, 181,
 182.
 group, 167.
 tritici, 184.
 Helmitheros vermivorus, 445.
 Helodromas solitarius solitarius, 439.
 Hemlocks, 336.
 Heptagenia, 52.
 Heron, Black-crowned Night, 438.
 Great Blue, 438.
 Green, 207, 215, 217, 438.
 Heteromeyenia argyrosperma, 13, 16,
 17.
 macouni, 17.
 pictouensis, 17.
 repens, 13, 15, 17.
 repens, var. 13.
 ryderi, 15, 17.
 Hexagenia, 52.
 bilineata, 54.
 Hicoria, 304, 308.
 glabra, 305.
 microcarpa, 305.
 odorata, 305.
 villosa, 305.
 laciniosa, 304.
 minima, 304.
 ovata, 304.
 pecan, 304.
 Hickories, 304, 308, 336.
 pignut, 305.
 water, 304.
 Hickory, 293, 297, 299, 304, 313, 315,
 316, 326, 341, 344, 345, 346, 351,
 359.
 Big Scaly Bark, 304.
 Big Shellbark, 304.
 Bitternut, 304.
 Eastern Pignut, 305.
 Pecan, 304.
 Shagbark or Shellbark, 304.
 Hirundo erythrogastra, 444.
 Holcus sorghum, 138.
 sorghum sudanensis, 138.
 sp., 138.

- Hornbeam, Hop, 311, 312.
 Hummingbird, Ruby-throated, 441.
 Hyalella, 45, 47.
 knickerbockeri, 52.
 Hydrochelidon nigra surinamensis,
 438.
 Hydropsyche sp., 45, 52, 54.
 Hylocichla aliciae aliciae, 448.
 fuscescens fuscescens, 447.
 guttata pallasi, 448.
 mustelina, 447.
 ustulata swainsoni, 448.

I

- Icteria virens virens, 446.
 Icterus galbula, 442.
 spurius, 442.
 Idae, 13.
 Insects, 7, 45, 46, 47, 48, 49, 53, 58, 67,
 69, 73, 207.
 Inzengaea, 109.
 Iridoprocne bicolor, 444.
 Isopoda, 36, 45, 71.
 Ixobrychus exilis, 438.

J

- Judas-tree, 311.
 Juglans, 308.
 cinerea, 308.
 nigra, 308.
 Junco, 400, 401, 402, 407, 408, 409, 410,
 411, 412, 413, 414, 416, 418, 419,
 420, 421, 422, 423, 428, 429, 431.
 See also Junco, Slate-colored.
 hyemalis hyemalis, 443.
 Slate-colored, 408, 409, 410, 411, 412,
 413, 427, 428, 429, 432, 443.
 Juniperus virginiana, 307.

K

- Killdeer, 194, 197, 201, 207, 214, 217,
 419, 427, 428, 432, 439.
 Kingbird, 193, 194, 197, 201, 202, 213,
 214, 217, 432, 441.
 Kingfisher, Belted, 440.
 Kinglet, Golden-crowned, 420, 421, 428,
 447.
 Ruby-crowned, 447.

L

- Lanius ludovicianus migrans*, 444.
Lanivireo flavifrons, 445.
 solitarius solitarius, 445.
Larches, 336.
Lark, Horned, 399, 416, 441.
 Prairie Horned, 193, 195, 196, 197,
 198, 200, 201, 202, 203, 205, 206,
 214, 215, 217, 400, 401, 402, 408,
 409, 410, 411, 414, 416, 418, 419,
 420, 421, 423, 427, 428, 429, 431,
 432, 441.
Larus argentatus, 438.
Leeches, 36, 45, 52, 54, 67, 71.
Lemon, 158.
Lepomis cyanellus, 385 (opposite),
 386.
 humilis, 385 (opposite), 386.
 megalotis, 385 (opposite), 386.
Libellula pulchella, 385.
Libellulidae, 52.
Lioplax subcarinata, 36, 37, 50, 55, 60.
Liquidambar styraciflua, 305.
Liriodendron tulipifera, 303.
Locust, 299.
 Black, 309, 336.
 Honey, 309, 336.
 Water, 316.
 -borer, 309.
Longspur, Lapland, 399, 400, 401, 402,
 406, 407, 408, 409, 411, 416, 419,
 420, 421, 432, 442.
 Smith's, 419, 421, 423, 443.

M

- Macrorhamphus griseus griseus*, 439.
Magnolia acuminata, 308.
 grandiflora, 327.
Mallard, 438.
Maple, 293, 313, 314, 315, 316, 331, 339.
 Hard, 297, 303, 307, 308, 336, 339.
 Red, 360.
 Soft, 293, 297, 299, 302, 307, 308, 336,
 337, 339.
Maples, 308.
Marila affinis, 438.
Martin, Purple, 444.

- May-beetles*, 195, 196, 201.
Meadowlark, 193, 194, 195, 196, 197,
 198, 200, 201, 202, 203, 204, 205,
 206, 210, 211, 212, 213, 214, 215,
 217, 397, 400, 407, 408, 410, 411,
 414, 416, 418, 419, 420, 421, 422,
 423, 427, 428, 429, 431, 432, 442.
Melanerpes erythrocephalus, 441.
Meliola, 129.
Melons, 291.
Melospiza georgiana, 444.
 lincolni lincolni, 443.
 melodia melodia, 443.
Meyenia calumetica, 12, 13.
 fluviatilis, 11, 12, 13.
Micropterus dolomieu, 385 (opposite),
 386.
 salmoides, 385 (opposite), 386.
Midges, larval, 36, 38, 41, 44, 45, 49,
 57, 64, 65, 66, 72. See also *Chiro-*
 nomidae.
Mildews, powdery, 165.
Millet, 170, 183.
 common, 138.
 German, 138.
Mimus polyglottos polyglottos, 446.
Minnow, Mud, 368.
Minnnows, 385.
Mniotilta varia, 445.
Mockingbird, 4, 194, 197, 198, 209, 210,
 211, 214, 215, 217, 427, 433, 446.
Mollusca, 36, 40, 45, 53, 54, 68, 71.
Molothrus ater ater, 442.
Morus rubra, 305.
Mosquitoes, anopheline, 23, 26, 27, 28,
 30.
 culicine, 23, 26, 27.
 malarial, 23-32.
Mucor, 161.
 genevensis, 161.
Mulberry, 293, 313, 317, 346.
 Red, 305, 336.
Musculium jayanum, 37, 50, 60.
 transversum, 36, 37, 38, 50, 55, 59,
 60, 71.
Mycosphaerella, 107.
Myiarchus crinitus, 441.
Myiochanes virens, 441.

N

- Nannius hiemalis hiemalis, 447.
 Nelumbo, 72.
 Nematodes, 79, 124.
 Nighthawk, 441.
 Nitela, 13.
 Notropis cornutus, 384, 385 (opposite), 386.
 umbratilis 385 (opposite).
 whippilii, 385 (opposite), 386.
 Nuthatch, Red-breasted, 447.
 White-breasted, 412, 413, 414, 428, 447.
 Nuthatches, 416.
 Nycticorax nycticorax naevius, 438.
 Nymphaea, 72.
 Nyssa aquatica, 305.
 sylvatica, 305, 306.

O

- Oak, Black, 293, 297, 303, 304, 313, 314, 315, 316, 326, 344, 345, 346, 350, 351, 357, 362, 368, 369, 371-376.
 Black-jack, 302.
 Bur, 299, 302, 340.
 Cow, 302.
 Pin, 299, 303.
 Post, 302, 326.
 Red, 299, 303, 339, 363.
 Scarlet, 303.
 Shingle, 303.
 Sour, 303.
 Spanish, 303.
 Swamp White, 297, 302, 305.
 Water, 303.
 White, 293, 297, 299, 302, 303, 313, 314, 315, 316, 326, 329, 337, 340, 344, 345, 346, 350, 351, 357, 361, 367, 370, 371-375, 377.
 Yellow, 303.
 Oak-hickory type of forest, 298, 343.
 Oaks, "black," 303.
 "red," 336.
 "white," 302, 336, 340.
 "willow," 303.
 Oats, 90, 91, 125, 126, 137, 138, 139, 182.
 Odonata, 36, 52, 54, 67.

- Oidium, 109.
 Oligochaeta, 46, 47, 48, 52, 53, 57, 58, 66, 69, 71, 73.
 Ophiobolus graminis, 77.
 Oporornis formosus, 446.
 philadelphia, 446.
 Oriole, Baltimore, 442.
 Orchard, 4, 194, 197, 198, 209, 210, 211, 214, 215, 217, 432, 442.
 Orthocladus sp., 42.
 Osage Orange, 305, 309.
 Osprey, 440.
 Ostrya virginiana, 312.
 Otocoris alpestris alpestris, 441.
 alpestris praticola, 441.
 Otus asio naevius, 440.
 Oven-bird, 446.
 Owl, Barred, 440.
 Long-eared, 440.
 Saw-whet, 440.
 Screech, 440.
 Short-eared, 440.
 Oxyechus vociferus, 439.

P

- Palpomyia sp., 72.
 longipennis, 51, 56, 64, 65, 72.
 Paludicella, 57.
 Pandion haliaetus carolinensis, 440.
 Parnidae, 52.
 Passer domesticus, 414, 442.
 Passerculus sandwichensis savanna, 443.
 Passerella iliaca iliaca, 444.
 Passerherbulus henslowi henslowi, 443.
 lecontei, 443.
 nelsoni nelsoni, 443.
 Passerina cyanea, 444.
 Peach orchards, 291.
 Pecan, 331.
 Penicillium, 137, 163, 165, 166, 170.
 Penthestes atricapillus atricapillus, 447.
 carolinensis carolinensis, 447.
 Perch, 387.
 Peronospora, 136, 165.
 parasitica, 165.

- Persimmon, 303, 311, 343, 346.
 Pestalozzia guepini, 165-66.
 Petrochelidon lunifrons lunifrons, 444.
 Peucaea aestivalis bachmani, 443.
 Pewee, Wood, 208, 211, 214, 217, 441.
 Phalacrocorax auritus auritus, 438.
 Philohela minor, 438.
 Phleum, 165.
 Phloeotomus pileatus abieticola, 441.
 Phoebe, 419, 441.
 Phryganeidae, 36, 52.
 Phycomyces, 160.
 Phyllophaga, 196.
 Phyllosticta, 78, 79, 161.
 pirina, 166.
 Physa spp., 37, 50, 60.
 Physidae, 36, 37, 50, 60.
 Pimephales notata, 385 (opposite), 386.
 Pine, Longleaf, 306.
 Shortleaf, 302, 306, 326.
 Southern, 334, 340.
 Yellow, 341.
 Pines, 336.
 Pintail, or Pintail Duck, 419, 438.
 Pinus echinata, 306.
 palustris, 306.
 Pipilo erythrophthalmus erythrophthalmus, 444.
 Pipit, 398, 421, 422, 427, 428, 429, 446.
 Piranga rubra rubra, 444.
 olivacea, 444.
 Pisidium sp., 37, 60.
 Pissobia maculata, 439.
 Planarians, 36, 45, 52, 54.
 Planesticus migratorius migratorius, 448.
 Planorbinae, 36, 37, 50, 60.
 Planorbis parvus, 50.
 spp., 37.
 trivulvis, 50, 60.
 Plasmopara, 165.
 Platanus occidentalis, 311.
 Plectrophenax nivalis nivalis, 442.
 Pleiomeyenia calumeticus, 12.
 Pleospora, 162.
 Pleurocera sp., 36, 37, 50, 55, 59.
 Pleuroceridae, 37, 38, 39, 45, 46, 47, 48, 49, 50, 53, 54, 55, 58, 62, 63, 69, 73.
 Plover, Golden, 423, 439.
 Upland, 192, 193, 202, 207, 214, 216, 217, 439.
 Podilymbus podiceps, 438.
 Polioptila caerulea caerulea, 447.
 Pomoxis annularis, 386.
 Poecetes gramineus gramineus, 443.
 Poplar, Swamp, 310.
 Yellow. See Tulip-tree.
 Populus deltoides, 311.
 heterophylla, 310.
 Porzana carolina, 438.
 Potamogeton, 46, 72.
 pectinatus, 70.
 Potato, 158.
 Prairie Chicken, or Prairie Hen, 408, 416, 417, 418, 420, 427, 439.
 Procladius concinnus, 56, 65, 72.
 culiciformis, 72.
 sp., 65.
 Progne subis subis, 444.
 Protonotaria citrea, 445.
 Prunus serotina, 309.
 Pteridophytes, 158.
 Puccinia, 136.
 epilobii-tetragoni, 165.
 graminis, 165.
- Q**
- Quail. See Bob-white.
 Quercus alba, 302.
 coccinea, 303.
 falcata, 303.
 imbricaria, 303.
 macrocarpa, 302.
 marilandica, 303.
 michauxii, 302.
 minor, 302.
 palustris, 303.
 platanoides, 302.
 rubra, 303.
 velutina, 303.
 Querquedula discors, 438.
 Quiscalus quiscula aeneus, 442.

R

- Rail, King, 438.
 Virginia, 438.
 Rallus elegans, 438.
 virginianus, 438.
 Redbud, 311.
 Redpoll, 399, 442.
 Redstart, 208, 211, 446.
 Redtop, 138.
 Redwood, 336.
 Regulus calendula calendula, 447.
 satrapa satrapa, 447.
 Rhizoctonia, 124.
 Rhytisma, 165.
 Rice, 87.
 Riparia riparia, 444.
 Robin, 4, 191, 193, 194, 195, 196, 197,
 198, 200, 201, 202, 203, 207, 208,
 209, 210, 211, 214, 217, 397, 416,
 418, 419, 421, 422, 423, 428, 429,
 431, 433, 448.
 Robinia pseudacacia, 309.
 Root-rot of Wheat, 139.
 Rusts, 165.
 Rye, 90, 125, 126, 137, 138, 183.

S

- Salix nigra, 311.
 Sandpiper, Buff-breasted, 421, 439.
 Pectoral, 439.
 Solitary, 439.
 Spotted, 439.
 Saprolegnia, 108.
 Sapsucker, Yellow-bellied, 440.
 Sassafras, 303, 313, 315, 343.
 sassafras, 309.
 Sayornis phoebe, 441.
 Scirpus, 46.
 Sclerotinia libertiana, 132.
 Sedge, 347.
 Seiurus aurocapillus, 446.
 motacilla, 446.
 noveboracensis notabilis, 446.
 Septoria, 78, 97, 165, 166.
 Setophaga ruticilla, 446.
 Shrike, Migrant, 419, 427, 444.
 Sialia sialis sialis, 448.

- Siskin, Pine, 442.
 Sitta canadensis, 447.
 carolinensis carolinensis, 447.
 Sludge-worms, 36, 38, 44-45, 46, 49,
 52, 57, 66, 71.
 Smartweed, 388.
 Smuts, 134.
 cereal, 135, 181.
 Snails, 36-40, 45, 49, 50, 52, 53, 54, 55,
 57, 59-63, 68-69, 71, 73.
 Snipe, Wilson's, 398, 419, 420, 438.
 "Softwoods," 293, 297, 302, 331, 350.
 Somatogyrus sp., 37, 50, 60.
 Sora, 438.
 Sorghum, 138, 170, 183.
 Sorghums, 138.
 Sparrow, Bachman's, 443.
 Chipping, 427, 443.
 English, 190, 191, 193, 194, 195, 196,
 197, 198, 200, 201, 202, 203, 205,
 206, 207, 208, 209, 210, 211, 212,
 213, 214, 215, 216, 217, 400, 401,
 402, 406, 407, 408, 409, 410, 412,
 413, 414, 416, 417, 418, 419, 420,
 421, 422, 423, 425, 428, 429, 432,
 442.
 Field, 4, 6, 7, 193, 194, 197, 198, 200,
 201, 208, 209, 210, 211, 212, 213,
 214, 215, 217, 412, 421, 422, 427,
 428, 432, 443.
 Fox, 413, 427, 444.
 Grasshopper, 192, 193, 194, 196, 197,
 198, 201, 202, 214, 217, 427, 428,
 432, 443.
 Henslow's, 427, 443.
 Lark, 197, 198, 214, 217, 432, 443.
 Leconte's, 443.
 Lincoln's, 427, 443.
 Nelson's, 443.
 Savannah, 421, 422, 427, 443.
 Song, 215, 217, 400, 409, 412, 413,
 414, 416, 418, 427, 429, 432, 443.
 Swamp, 414, 427, 428, 444.
 Tree, 400, 401, 402, 406, 407, 408,
 409, 410, 411, 412, 413, 414, 416,
 418, 419, 420, 421, 427, 432, 443.

Sparrow—*Continued*.

- Vesper, 196, 197, 198, 206, 214, 217,
419, 421, 422, 427, 428, 432, 443.
White-crowned, 427, 443.
White-throated, 401, 427, 428, 429,
431, 443.
Spartina, 165.
Sphaeriidae, 36, 37, 38, 39, 46, 47, 48,
49, 50, 53, 54, 55, 58, 60, 62, 63, 69,
73.
Sphaerium simile, 50.
stamineum, 37, 50, 55.
striatinum, 37, 50.
Sphyrapius varius varius, 440.
Spinus pinus, 442.
Spiza americana, 444.
Spizella monticola monticola, 443.
passerina passerina, 443.
pusilla pusilla, 210, 443.
Sponges, fresh-water, 9-22, 36, 45, 52,
57.
Spongilla aspinosa, 17.
fragilis, 13, 14, 15, 16, 17.
calumetica, 13.
heterosclerifera, 17.
igloviiformis, 14, 16, 17.
lacustris, 13, 14, 15, 16, 17.
mackayi, 17.
novae terrae, 17.
wagneri, 17.
Sporobolus, 121.
Spruces, 336.
Stelgidopteryx serripennis, 444.
Stenelmis, 52, 57.
Sterigmatocystis, 137.
Strix varia varia, 440.
Sturnella magna magna, 442.
Stysanus, 165.
Sudan grass, 138, 170.
Sugar-cane, 138.
Sumach, 343.
Sunfish, 387.
Swallow, Bank, 444.
Barn, 193, 196, 197, 198, 201, 202,
214, 217, 433, 444.
Cliff, 203, 214, 217, 444.
Rough-winged, 444.
Tree, 444.

- Swift, Chimney, 211, 214, 217, 441.
Sycamore, 297, 302, 311, 316, 331, 332,
333, 336, 337, 351.
Synchitrium, 165.

T

- Take-all, 77.
Tanager, Scarlet, 444.
Summer, 444.
Tanypus dyari, 40, 42, 72.
illinoensis, 51.
monilis, 51, 56, 65, 72.
Taphrina, 165.
Taxodium distichum, 306.
Teal, Blue-winged, 438.
Telmatodytes palustris palustris, 447.
Tern, Black, 438.
Thrasher, Brown, 4, 5, 6, 7, 190, 193,
194, 195, 197, 198, 201, 206, 208,
209, 210, 211, 213, 214, 217, 433,
446.
Thrush, Gray-cheeked, 448.
Hermit, 448.
Olive-backed, 448.
Wood, 208, 447.
Thryomanes bewicki bewicki, 447.
Thryothorus ludovicianus ludovicianus,
447.
Tilia, 309.
americana, 309.
Titmouse, Tufted, 208, 211, 214, 217,
400, 411, 412, 413, 414, 422, 428,
433, 447.
Toad eggs and embryos, 379, 381, 385.
Tomatoes, 291.
Totanus flavipes, 439.
melanoleucus, 439.
Towhee, 208, 210, 211, 214, 215, 217,
422, 427, 444.
Toxostoma rufum, 446.
Trichoptera, 71.
Trochospongilla horrida, 14, 17.
leidyi, 14, 15, 17.
Troglodytes aedon parkmani, 447.
Tryngites subruficollis, 439.
Tubella pennsylvanica, 14, 15, 16, 17.
Tubifex, 44, 52, 57, 66.

- Tubificidae, 36, 44, 52, 57, 66.
 Tulip-tree, 293, 297, 299, 303, 309, 313,
 314, 315, 316, 331, 332, 346, 351,
 352, 358.
 Tupelo, 299, 305, 306, 308, 332.
 Tympanuchus americanus americanus,
 439.
 Tyrannus tyrannus, 441.

U

- Ulmus .alata, 310.
 americana, 310.
 pubescens, 310.
 serotina, 310.
 Unionidae, 50, 57.
 Uromyces, 165.
 Utricularia, 12, 13.

V

- Vallisneria, 46.
 Valvata bicarinata, 37, 50, 60.
 spp., 36.
 tricarinata, 37, 50, 60.
 Valvatidae, 37, 38, 39, 46, 47, 48, 50, 53,
 58, 60, 62, 63, 69, 73.
 Veery, 447.
 Vermivora celata celata, 445.
 peregrina, 445.
 pinus, 445.
 rubricapilla rubricapilla, 445.
 Vireo belli belli, 445.
 Bell's, 445.
 Blue-headed, 445.
 griseus griseus, 445.
 Philadelphia, 444.
 Red-eyed, 444.
 Warbling, 444.
 White-eyed, 445.
 Yellow-throated, 445.
 Vireosylva, gilva gilva, 444.
 olivacea, 444.
 philadelphica, 444.
 Vivipara contectoides, 36, 37, 50, 55, 60.
 subpurpurea, 37, 50, 55, 59, 60.
 Viviparidae, 36, 37, 38, 45, 46, 47, 48,
 49, 50, 53, 54, 55, 58, 60, 62, 63,
 69, 73.

- Vulture, Black, 439.
 Turkey, 208, 400, 410, 411, 427, 432,
 439.

W

- Walnut, 293, 316.
 Black, 297, 299, 308, 313, 314, 315,
 336.
 "Satin," 305.
 White, 308.
 Walnuts, 308.
 Warbler, Black and White, 208, 445.
 Blackburnian, 446.
 Black-poll, 446.
 Black-throated Blue, 445.
 Green, 446.
 Blue-winged, 445.
 Canada, 446.
 Cape May, 445.
 Chestnut-sided, 445.
 Hooded, 446.
 Kentucky, 446.
 Magnolia, 445.
 Mourning, 446.
 Myrtle, 427, 428, 445.
 Nashville, 445.
 Northern Parula, 445.
 Orange-crowned, 445.
 Palm, 446.
 Pine, 446.
 Prothonotary, 445.
 Swainson's, 445.
 Sycamore, 446.
 Tennessee, 445.
 Worm-eating, 445.
 Yellow, 445.
 Water-Thrush, Grinnell's, 446.
 Louisiana, 446.
 Water-lilies, White, 388.
 Yellow, 388.
 Waxwing, Bohemian, 444.
 Cedar, 444.
 Wheat, 90, 91, 125, 126, 128, 138, 139,
 170, 181, 182, 183, 184, 185, 291.
 Arnautka, 182.
 De, 183.
 foot-rot, 77-139.
 Golden Chaff, 131.

Wheat—*Continued.*

- Marquis, 181.
- Red Durum, 182.
- seedling blight, 139.
- Sultzer Pride, 124.

Whip-poor-will, 441.

Whitefish eggs, 379, 381, 385.

Willow, 293, 294, 299, 334, 337, 340, 350.

- Black, 311, 364.

- White, 311.

- fly nymphs, 54.

Willows, 311.

Wilsonia canadensis, 446.

- citrina, 446.

Woodcock, 438.

Woodpecker, Downy, 208, 214, 215, 217, 412, 413, 414, 427, 440.

- Hairy, 413, 414, 440.

- Northern Pileated, 441.

- Red-bellied, 413, 414, 441.

- Red-headed, 190, 193, 194, 195, 197, 198, 201, 206, 208, 210, 211, 213, 214, 215, 217, 407, 416, 427, 432, 441.

Woodpeckers, 416.

- Worms, 45, 46, 47, 48, 49, 53, 58, 67, 69, 73.

Wren, Bewick's, 208, 428, 447.

- Carolina, 447.

- Long-billed Marsh, 207, 215, 217, 447.

- Short-billed Marsh, 213, 215, 217, 447.

- Western House, 447.

- Winter, 447.

Y

Yeasts, 158.

- Yellow-breasted Chat, 210, 214, 217, 446.

Yellow-legs, 439.

- Greater, 439.

- Yellow-throat, Maryland, 194, 197, 198, 207, 208, 210, 212, 213, 214, 217, 433, 446.

Z

Zamelodia ludoviciana, 444.

Zenaidura macroura carolinensis, 439.

Zonotrichia albicollis, 443.

- leucophrys leucophrys, 443.

STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION
DIVISION OF THE
NATURAL HISTORY SURVEY
STEPHEN A. FORBES, Chief

Vol. XIV.

BULLETIN

Article I.

THE ORCHARD BIRDS OF AN
ILLINOIS SUMMER

BY

STEPHEN A. FORBES
and
ALFRED O. GROSS



PRINTED BY AUTHORITY OF THE STATE OF ILLINOIS

URBANA, ILLINOIS

June, 1921

